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January 1999
NSRP 0525
N7-96-9

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Welding Fume Study
Final Report

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Halter Marine Group, Inc.

Report Documentation Page

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NATIONAL SHIPBUILDING
RESEARCH PROGRAM

NAME PRODUCTION COMMITTEE
SP-7 Welding
7-96-9

WELDING FUME STUDY
FINAL REPORT

January 28, 1999

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EXECUTIVE SUMMARY

In anticipation of the lowering of OSHA permissible exposure limits (PEL) for several compounds found in welding fume in the near future, Panel SP-7 of the National Shipbuilding Research Program contracted with DynCorp to identify and evaluate the economic and workplace impact of the lowered limits by examining welding processes used in the shipbuilding industry, gathering air sample data, and addressing the impact of the anticipated reduction. It is anticipated that the PEL for hexavalent chromium will be reduced from the current level of 100 micrograms per cubic meter (ug/m3) to between 0.5 - 5.0 ug/m3 and that a the PEL will be established for manganese at 200 ug/m3.

A total of three interim deliverables were produced during this project. Task No. 1 - Information Search is presented in Appendix 1. Task No. 2 - Regulatory Impact Analysis is presented in Appendix 2. Task No. 3 - Field Evaluations is presented in Appendix 3. Photographs collected during site visits are presented in Appendix 4.

Six engineering control methods were selected for evaluation based upon the Information Search and commercial availability. The six methods selected were fume extractor guns, fixed fume extraction systems, portable fume extraction systems, low fume welding wires, downdraft/backdraft tables, and fume filtration devices. No single engineering control observed consistently reduced worker fume exposures to levels below the lowest anticipated OSHA PEL reductions. The annual cost of compliance for each shipyard worker is estimated at $24,094 if the PEL for Cr6 is reduced to 0.5 ug/m3. This cost estimation, completed in 1997, does not include the anticipated cost impact of the new OSHA Respiratory Protection Standard, which became effective April 8, 1998.

There have not been any significant changes in the design of widely used welding fume engineering controls found in the shipbuilding industry over the past five years. If the anticipated OSHA PEL changes are made, shipyards will face increased operational and overhead compliance costs through personal protective equipment, lost productivity, engineering controls, and general compliance safety programs. It is likely that a reduction in the OSHA PEL for welding fumes would stimulate new technological innovations for engineering controls.

The shipbuilding industry should consider future ramifications associated with the proposed reductions of welding fume exposure limits. It is also possible that more stringent environmental regulations will be issued requiring capture and disposal of welding fumes. Standardizing the collection method for air sample data would provide the shipbuilding industry with a valuable tool when presenting compliance information to federal regulators. The shipbuilding industry should carefully assemble and present the information they have collected from reports such as this to formally respond to OSHA during the Comment Period for the proposed reduction of Cr6 scheduled for September, 1999.

1.0 Introduction and Background

1.1 Scope of Work

The Occupational Safety and Health Administration (OSHA) is expected to reduce the Permissible Exposure Limit (PEL) for several compounds found in welding fume in the near future. Panel SP-7 of the National Shipbuilding Research Program tasked DynCorp with identifying and evaluating the economic and workplace impact of the lowered limits by examining welding processes used in the shipbuilding industry, gathering air sample data for various welding processes, and addressing the development and impact of the proposed OSHA Standards.

1.2 Objective

The objectives of the Welding Fume Study included assessment of impact of proposed reductions in welding fume exposures on the shipbuilding industry, determination of compliance methods required to meet proposed regulations and technical feasibility of the compliance methods identified, and defining the development need for new control technology and engineering changes required to meet the new standard.

1.3 Background

OSHA has been evaluating the effects of workplace exposures to Cr6 and Mn in anticipation of reducing the current PELs. Additionally, the American Conference of Governmental Industrial Hygienist (ACGIH) reduced the Threshold Limit Value (TLV) of Ni in 1997, which is likely to impact the OSHA PEL evaluation.

FUME	CURRENT OSHA LIMIT	ANTICIPATED OSHA LIMIT
Cr6	100 ug/m3 PEL	0.5 - 5.0 ug/m3 PEL
Mn	5000 ug/m3 - Ceiling Limit (15 min)	200 ug/m3 PEL
Ni	1000 ug/m3 PEL	200 ug/m3 PEL

Cr6 has been the subject of regulatory controversy for many years. In 1975, the National Institute for Occupational Safety and Health (NIOSH) published and forwarded to OSHA a document containing recommendations for a Cr6 standard. The document made a distinction between noncarcinogenic Cr6 and carcinogenic Cr6 compounds. The two classes of Cr6 had their own standards. The carcinogenic compounds were to be controlled in the workplace so that the airborne Cr6 concentration levels would not exceed 1.0 micrograms per cubic meter of air (ug/m^3). The noncarcinogenic compounds were to be controlled in the workplace so that airborne Cr6 concentration levels would not exceed 25 ug/m^3 as an eight hour Time Weighted Average (TWA). The current OSHA PEL for Cr6 compounds is 100 ug/m3 of air for an eight hour TWA.

In 1988, NIOSH representatives testified at OSHA's informal hearings on the Air Contaminants Standard, they declared that new scientific evidence indicated that all Cr6 compounds should be considered as potential occupational carcinogens for regulatory purposes. They urged OSHA to adopt the most protective of the available standards for Cr6 compounds. In the Air Contaminants Standard, OSHA stated that Cr6 is carcinogenic, but placed the issuance of a lower PEL on hold due to the complexity of the issues involved.

On July 19, 1993, Public Citizen Health Research Group and the Oil, Chemical, and Atomic Workers International (OCAW) Union filed a petition to the Assistant Secretary for OSHA requesting a reduced tolerance for Cr6 through an Emergency Temporary Standard (ETS) issued under the authority of the Occupational Safety and Health Act. The petitioners requested that OSHA lower the PEL for Cr6 from 100 ug/m^3 to 0.5 ug/m^3. On March 8, 1994, following a thorough evaluation, OSHA denied the petition for an ETS.

On April 4, 1994, OSHA announced that a proposed rule to reduce the Cr6 PEL from 100 ug/m3 to between 0.5 ug/m^3 and 5.0 ug/m^3 was expected to be published in March, 1995. The proposed rule for Cr6 was not published in 1995, and OSHA set the new date for publishing the proposed rule for September, 1999. In October, 1997, Public Citizen Health Research Group and the OCAW filed a lawsuit against OSHA in the US Court of Appeals 3rd Circuit Court in Philadelphia to enact the proposed rule sooner than September, 1999.

Health Effects associated with Cr, Cr6, Ni, and Mn are discussed below:

Chromium (Cr)

Cr is a cancer causing agent and a mutagen in humans. It has been shown to cause lung and throat cancer. Cr fumes can cause “metal fume fever,” a flu like illness lasting about 24 hours with chills, aches, cough, and fever. Cr particles can irritate the eyes. It is on the EPA Hazardous Substance List and is regulated by OSHA and cited by ACGIH, NTP, and IARC. Cr has been reported to cause lung allergy. Once allergy develops, even small future exposures may cause cough, wheezing, or shortness of breath.

Hexavalent Chromium (Cr6)

Cr6 is a carcinogen. Cr6 is irritating, and short-term, high-level exposure can result in adverse effects at the site of contact, such as ulcers of the skin, irritation of the nasal mucosa and perforation of the nasal septum, and irritation of the gastrointestinal tract. Cr6 may also cause adverse effects in the kidney and liver. Inhalation exposure to Cr6 may result in additional adverse effects on the respiratory system and may effect the immune system.

Nickel (Ni)

Ni is a carcinogen and may damage the developing fetus. Eye and skin contact may cause irritation. Fumes from heated Ni can cause a pneumonia-like illness, with cough and shortness of breath. Higher exposures can cause a build-up of fluid in the lungs (pulmonary edema), a medical emergency, with severe shortness of breath. There is a clear association between Ni refining and an increase in lung, nasal, and throat cancers in humans. Skin contact may cause a skin allergy, with itching, redness, and later rash. Lung allergy occasionally occurs with asthma-type effects. Single high or repeated lower exposures may damage the lungs. With scaring of lung tissues, and may cause damage to heart muscle, liver, and/or kidney. It is on the EPA Hazardous Substance List and is regulated by OSHA and cited by ACGIH, DOT, NIOSH, IARC, NTP, DEP, NFPA, and EPA.

Manganese (Mn)

Repeated exposure to Mn may cause gradual brain damage. There is limited evidence that Mn may decrease fertility in males. Early effects include sleepiness, weakness and poor appetite. If exposure is stopped at this stage, damage may be temporary. Later effects include changes in speech, a loss of facial expression, personality changes, poor muscle coordination, changes in walking, muscle cramps, twitching and tremors. When later changes occur, some permanent brain damage can result and symptoms are identical to Parkinson’s Disease. Repeated exposure can cause a variety of changes in the blood count. Liver and/or kidney damage may occur. High or repeated exposure may cause lung allergy (asthma) to develop with wheezing, shortness of breath. Once allergy develops, even low future exposures can cause symptoms.

2.0 Project Tasks & Approach

There were a total of three interim deliverables produced during the Welding Fume Study:

Task No. 1 - Information Search

Task No. 2 - Regulatory Impact Analysis

Task No. 3 - Field Evaluations

A copy of each interim deliverable is presented in the **Appendix 1**, **Appendix 2**, and **Appendix 3** of this report. The project tasks and approach for each Task are discussed in each report. Interim deliverable review comments received from SP-7 Panel members have been noted and addressed. Due to the large size of the Task No. 1 report, the articles have not been included and only the body of the report and the literature abstracts for the forty articles are presented.

Where permitted, a digital camera was used to record during the Field Evaluations phase of the project. Photographs of shipyard welding processes are presented in **Appendix 4**.

3.0 Results & Discussion

3.1 Current Engineering Control Methods

Six current engineering controls methods for welding fume control were identified for evaluation during this project. This included fume extractor guns, fixed fume extraction systems, portable fume extraction systems, low fume welding wires, downdraft/backdraft tables, and fume filtration devices. The Task No. 3 report provided evaluations of the available engineering controls. No participating shipyards were using downdraft/backdraft tables or portable fume filtration systems during Field Evaluations.

The observed engineering controls were effective in reducing welding fume exposure generated by the welding process. No single engineering control method offered the worker complete protection from welding fume.

3.2 Compliance Costs Associated with Exposure Reductions

The estimated shipyard cost per worker (annually) to comply with the current PEL of 100 ug/m3 for Cr6 is $2,509. The estimated shipyard cost per worker at a PEL of 10 ug/m3 is $8,461. The estimated shipyard cost per worker at a PEL of 5 ug/m3 is $18,321. The estimated shipyard cost per worker at a PEL of 0.5 ug/m3 is $24,094.

The increased burden of compliance may drive up US shipyard costs to a point where it will be significantly cheaper for commercial ship owners to have ship construction, repair, and maintenance activities performed in other countries. Since the US Navy is the predominant ship building, maintenance, and repair client for many shipyards, the compliance costs are likely to have major effects on the cost and efficiency of operations necessary for national security.

3.3 Current Exposure Controls and Alternatives

Each engineering control method evaluated provided some level of fume extraction capability. No single engineering control observed consistently reduced worker exposures to levels below the anticipated OSHA PEL reductions for welding fumes.

Several factors contribute to the difficulty in reducing worker exposures to welding fumes. One is the welding process itself. Current welding technology requires that the molten metal in the weld pool be protected by an inert shielding gas to prevent contamination of the weld. Engineering controls designed to capture welding fumes generated at the weld pool often remove the protective shielding gas also resulting in unacceptable weld quality and lost production time. Another difficulty is the nature of ship construction which often requires welders to work in very small spaces in close proximity to the fume source. The harsh environments in which ships operate often dictates the design selection of metals used to construct the ships. Many times substitutions of the types of metals and welding processes are not possible. Replacement metal with alternative materials or replacement of the welding process through use of alternative technologies to bond metals together is not likely in the near future.

OSHA does not recognize respiratory protection equipment as an acceptable alternative to engineering controls for manufacturing operations. OSHA allows respiratory protection as means of compliance only when an employer can demonstrate that effective engineering controls are not technically or economically feasible. There is a large selection of respiratory protection equipment designed to accommodate welders available on the commercial market.

Some participating shipyards were making visible efforts to reduce worker exposures to fume emissions by fume extraction guns, powered air purifying respirators built into the welding helmets, and portable ventilation systems. The use of robotic welders, the substitution of welding processes, or the substitution of materials for the specific purpose of reducing welding fumes exposures was not observed during this study.

4.0 Conclusions and Recommendations

4.1 Conclusion of Information Search

The Information Search was a comprehensive examination of the current technology and work methods available to reduce worker exposure to welding fumes. There have been no significant changes in the design and widespread field application of welding fume engineering controls over the past five years, although there has been a general trend toward improving the conditions of the shipbuilding work environment to enhance worker safety and comfort.

Compliance requirements necessary to achieve the current OSHA PELs for welding fume elements provide little economic incentive for shipyards to allocate resources, make process changes, or implement engineering control solutions to reduce worker exposures to welding fume. Consequently, welding equipment manufactures have had little incentive to perform the research and development necessary to produce better control measures for welding fumes. This situation is likely to change as a result of the anticipated reduction of the OSHA PELs for welding fume as shipyards look to equipment manufactures to find more cost effective solutions to achieve compliance.

4.2 Conclusion of Regulatory Impact Analysis

The Regulatory Impact Analysis evaluated the status of proposed changes to OSHA PELs and ACGIH TLVs for exposures to welding fumes to determine what impact these regulatory changes may be expected to have on the shipyard welding industry.

Regulatory Impact Analysis findings included the following:

1. At a PEL of 5.0 ug/m^3 (Cr6), employers will need to provide respirator protection to welding trade workers for about 50% of ship building/repair/maintenance activities.

2. At a PEL of 0.5 ug/m^3 (Cr6), employers will need to provide respirator protection to welding trade workers for about 100% of ship building/repair/maintenance activity.

3. Protection of other workers in nearby work areas will require provision of isolation and ventilation system equipment for many welding/thermal cutting operations if the proposed exposure limit changes are implemented.

4. Proposed exposure limit changes will have major effects on the cost and efficiency of operations necessary for national security.

5. The proposed changes will lower the exposure limits to a point where a much higher rate of protection response will be needed.

6. A key element in the proposed rule changes is that employers must demonstrate and document a negative exposure assessment for all work tasks where protective action is not taken.

7. The proposed regulation changes will impose four broad categories of operational and overhead costs on employers:

   A. Personal Protective Equipment
   B. Lost Productivity
   C. Engineering Controls
   D. General Compliance Safety Program Costs

8. It is anticipated that costs for additional air monitoring (because of the negative exposure assessment requirement) and medical surveillance (because increased incidence of respirator use) will be the most significant elements of cost increase under the proposed rule changes.

9. Training costs are not expected to increase significantly, because most welders are already trained to use respirators.

10. Medical surveillance costs may also increase because higher incidence of situations requiring respiratory protection may result in more workers falling under that provision of the Cr6 rule.

11. A cost analysis was performed using four different PEL levels for Cr6 currently under consideration. The following is a breakdown of approximate costs per worker to comply with the proposed rule changes:

A. Current PEL of 100 ug/m^3 --> \$2,509.00
B. A PEL of 10 ug/m^3 --> \$8,461.00
C. A PEL of 5.0 ug/m^3 --> \$18,321.00
D. A PEL of 0.5 ug/m^3 --> \$24,094.00

4.3 Results and Conclusions of Field Evaluations

Shipyard work, as observed, involved the application of only limited special equipment and practices to control employee welding fume exposures. There are several engineering control methods available which can reduce welders exposure to welding fume, but no one control method consistently reduced worker exposures to levels below the lowest anticipated OSHA PEL reductions for Cr6 and Mn, 0.5 ug/m3 and 200 ug/m3, respectively. The current engineering controls observed during the Field Evaluations did not provide any one universal solution to controlling welding fume exposure primarily due to the wide variety of materials and environments encountered in shipyard welding. A combination of current engineering controls would help to reduce worker fume exposure levels, but effective use of personal protective equipment still appears necessary to provide adequate protection.

It is likely that a reduction in the OSHA PEL for welding fume elements would stimulate development of new technological innovations for welding fume engineering controls. Welding equipment vendors who were contacted indicated that increased market demand for such products would motivate them to dedicate additional resources for research and development of engineering control solutions.

Based upon observations from the Field Evaluation, DynCorp recommends the following:

1. Shipyards should consider the need to reduce fume exposures during the initial design phase of a ship construction project. This would include specifying materials that contain low levels of chrome and reducing or eliminating the use of welding processes that generate large amounts of fume.

2. Existing fume extraction systems should be reevaluated to determine if their design and operation can be improved for wider acceptability and application. Input from welders should be solicited.

3. Workers should be carefully trained to use fume extraction equipment properly. Supervisors should be trained to evaluate employee performance based upon the employee’s demonstrated ability to use the equipment properly and consistently.

4. An industry standard should be established for classification of Low Fume Welding Wires.

5. Each shipyard visited made respirators available to their welders, but welders were often observed either not using the respirators or using respirators equipped with filters which were not designed to capture fumes. Proper selection and use of respirators should be a regular part of employee training and evaluation.

4.4 Recommendations

After the more stringent PELs for welding fumes are implemented, it is possible that future federal regulations will be developed that specify requirements for capture and proper disposal of welding fumes. The shipbuilding industry should carefully consider this matter when selecting and integrating engineering controls into shipyard facilities.

Current OSHA personal air sample collection requirements specify that the filter cassette be fixed in place inside the welders helmet. This requires that the air sample cassette, hose and pump be removed each time the welder takes off the helmet to perform other routine work tasks, such as chipping and grinding, that are performed in conjunction with welding. Also, air sample cassettes cannot be mounted in the required manner for tack welders, who use shorty style helmets or hand held shields, or welders wearing goggles during cutting operations. The current air sample cassette placement specified by OSHA is impractical for field sampling. It is possible to achieve the same level of fume detection by positioning the air sample cassette high on the workers collar where it is protected by the face shield when the shield is lowered. An example of this is shown in photographs presented in Attachment D, page D-2 of the Task No. 3 - Field Evaluations report. This method of placement keeps the sample cassette in the welders breathing zone without impeding the welders production rate by having to remove and reinstall the sampling equipment several times per hour. The shipbuilding industry should consider bringing this matter to the attention of OSHA during the comment period for the proposed PEL reduction for Cr6.

Air sample data which was provided by participating shipyards varied tremendously in the type of information which was collected for each sample. Some shipyards collected detailed information regarding the type of welding performed, personal protective equipment used, engineering controls provided, etc., and some recorded only the welders name. Development of an industry standard for air sample data collection elements would allow direct comparison of results from shipyard to shipyard. This would provide the shipyard industry with a valuable tool when presenting information to federal regulators to support a position.

The proposed reduction of the Cr6 PEL by OSHA is likely to be published in September, 1999. The shipbuilding industry should begin to organize and develop a group to respond to OSHA during the Comment Period, which is typically 60 to 90 days. Information gathered by NSRP through efforts such as this report and others should be carefully assembled and presented during the Comment Period in a format which maximizes the quality of information collected and the processes evaluated. During the Comment Period the NSRP should also deliver a written request for a Hearing. NSRP should assemble expert witnesses and develop a specific agenda for the Hearing. This process is often very influential in the outcome of the final regulations.

Final Report

Appendix 1

February 14, 1997

Mr. John Meacham
Program Manager
Peterson Builders, Incorporated
Industrial Engineering Department
101 Pennsylvania Avenue
Sturgeon Bay, WI 54235

Subject: Task No. 1 Report, NSRP Project 7-96-9, Welding Fume Study

Mr. Meacham:

Attached is the Task No. 1 Report, Information Search, prepared by DynCorp in accordance with Project 7-96-9.

DynCorp has made substantial progress towards the completion of Task 2, Regulatory Impact Analysis, with completion projected for March 14, 1997. Work on Task 3, Field Evaluations, will begin as scheduled on February 14, 1997.

If you have any questions or require additional information, please call me at (703) 264-8770.

Sincerely,

Daniel O. Chute, CIH, CSP
Director
Environmental Health & Safety Services

NATIONAL SHIPBUILDING
RESEARCH PROGRAM

SNAME SHIP PRODUCTION COMMITTEE
SP - 7 Welding
7 - 96 - 9

WELDING FUME STUDY
TASK NO. 1 - INFORMATION SEARCH
INTERIM DELIVERABLE

February 14, 1997

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1.0 Introduction:

The purpose of Task 1, Information Search, of the Welding Fume Study was to collect and review technical literature related to worker exposures to welding fumes of chromium (Cr), nickel (Ni) and manganese (Mn). Information was collected through the use of on-line searches, telephone queries, library research and a shipyard survey.

DynCorp set specific parameters for the Literature Search. Current information sources were consulted and emphasis was placed on the following:

*Welding processes and consumables
*Data on the composition of welding fumes
*Sources of occupational exposure data on Cr, Ni and Mn
*Proposed regulatory changes affecting occupational exposure to Cr, Ni and Mn
*Control measures currently used
*New and promising technology
*Process modification

2.0 Information Search:

DynCorp conducted an Internet search for documents related to welding and welding fume data. The internet search led to contact with Mr. John Bishop at the Navy Environmental Health Center, Mr. Harvey Castner at the Navy Joining Center, and Mr. Ren Brenner at the Naval Surface Warfare Center. Mr. Bishop, Mr. Castner and Mr. Brenner wrote or participated in several articles which are included in this report and provided valuable technical assistance.

DynCorp contacted over 25 welding equipment and supplies manufacturers to obtain product literature information on the latest fume extraction, fume reduction and personal protective equipment. DynCorp did not discover any new technologies being developed for fume extraction. Listed below are the common fume control methods readily available from manufacturers:

1. Fume extractor guns
2. Fixed fume extraction systems
3. Portable fume extraction systems
4. Low fume welding wires
5. Downdraft/Backdraft tables
6. Fume filtration devices

DynCorp worked through Mr. Castner at the Navy Joining Center to access Weldasearch, The Materials Joining Database, maintained by The Welding Institute (TWI). The Weldasearch database contains more than 145,000 bibliographic references related to the welding industry.

DynCorp's Weldasearch queries were limited to English language documents published since 1991 that matched the following key words: health, safety, fume, ventilation, chromium, nickel, and manganese. This search yielded a total of 209 publications. Mr. Castner also provided an additional list of 63 publications that he felt were applicable to the scope of the project.

DynCorp sorted through the hundreds of publications to determine the most applicable documents. A total of forty publications were selected for inclusion in this report. DynCorp obtained copies of the reports from the University of Maryland Engineering & Chemistry libraries, the National Institutes of Health Medical Research Library, the Carderock Naval Surface Warfare Center Facility technical library, the Navy Joining Center technical library, the DynCorp research library, and through direct contact with publishers and authors.

Although emphasis was placed on collecting information published within the past five years, some older articles of relevance are included. Each of the forty articles is preceded by a brief abstract prepared by DynCorp. Listed below are the articles selected for this report in footnote format. The articles are grouped by year, beginning with the most recent publications. The number next to the article corresponds to the numbered tabs in the report:

1. The Navy Joining Center and A Navy/Industry Task Group, Impact of Recent and Anticipated Changes in Airborne Emission Exposure Limits on Shipyard Workers, National Shipbuilding Research Program, March 1996.

2. John Bishop, Workshop Session 1996 Chromium (VI) Update: Impact of OSHA and Navy Initiatives Hexavalent Chromium Exposure Evaluation, Navy Environmental Health Center, 1996.

3. John Bishop, Health Standard for Manganese, Navy Environmental Health Center, 1996.

4. Navy/Industry Task Group, Impact of Anticipated OSHA Hexavalent Chromium Worker Exposure Standard On Navy Manufacturing And Repair Operations, National Shipbuilding Research Program, October 1995.

5. Paul Hewett, "The Particle Size Distribution, Density, and Specific Surface Area of Welding Fumes from SMAW and GMAW Mild and Stainless Steel Consumables", American Industrial Hygiene Association Journal, February 1995, p. 128 - 135.

6. Paul Hewett, "Estimation of Regional Pulmonary Deposition and Exposure for Fumes from SMAW and GMAW Mild and Stainless Steel Consumables", American Industrial Hygiene Association Journal, February 1995, p. 136 - 142.

7. Walter F. Emerson, "Guide for Selection of Fume Exhausters", Welding Design & Fabrication, February 1995, p. 19 - 24.

8. Harvey R. Castner, "Gas Metal Arc Welding Fume Generation Using Pulsed Current", Welding Journal, Vol. 74, No. 2, February 1995, p. 59s - 68s.

9. Stanley E. Ferree, "New Generation of Cored Wires Creates Less Fume and Spatter", Welding Journal, December, 1995, p. 45 - 49.

10. Hugh K. Webster, "Welding Could Become an OSHA Priority", Welding Journal, Vol. 74, No. 2, February 1995, p. 7.

11. "Fume Extractor Guns Clean the Air", Welding Design & Fabrication, February 1995, p. 26 -27.

12. Terry G. Eichman, "Respirator Selection for Metal-Fabricating Shops", Welding Design & Fabrication, April 1995, p. 45 - 47.

13. Hobart Institute of Welding Technology, "Fume Control System Helps Students Breathe Easier", Welding Journal, June 1995, p. 43 - 44.

14. PJ Blakely, "Welding Fume - Control and Guidance", Welding and Metal Fabrication, Vol. 63, October 1995, p. 378 - 380.

15. Andrew Cullison, "Take a Look at Fume Extracting Welding Guns", Welding Journal, September 1994, p. 35 - 37.

16. Jan Karlson, Torgrim Torgrimsen, Sverre Langard, "Exposure to Solid Aerosols During Regular MMA Welding and Grinding Operations on Stainless Steel", American Industrial Hygiene Association Journal, December 1994, p. 1149 - 1152.

17. "Shielding Gas, Wire Type Have Drastic Affect on Fume Emissions", Welding Design & Fabrication, July, 1994, p. 14.

18. Jorgen E. Rasmussen, Tedak AB, Eskilstuna, "High Vacuum Extraction of Welding Fumes Within the Shipbuilding Industry", Svetsaren, Vol. 48, No. 2, 1994, p. 19 - 21.

19. Mary Ruth Johnson, "Smoke Won't Get in Your Eyes in This Welding Lab", Welding Journal, September 1994, p. 59 - 61.

20. Hugh K. Webster, "OSHA Readies Itself for More Action", Welding Journal, September 1994, p. 7.

21. Craig Colton, "A Welders Guide to Respiratory Protection", Welding Journal, September 1994, p. 45-48.

22. "Coping with Welding Hazards", Welding and Metal Fabrication, Vol. 62, April 1994, p. 178 - 180.

23. Harvey R. Castner, Measurements of GMAW Fume Generation Rates Using Pulsed Welding Current, The Environment and the Joining Industry - Product Manufacture, Pollution Prevention, and Safety and Health. Proceedings, 9th Annual North American Welding Research Conference, Columbus, OH, October 1993.

24. Kenneth L. Brown, Development of Environmental Release Estimates for Welding Operations, The Environment and the Joining Industry - Product Manufacture, Pollution Prevention, and Safety and Health. Proceedings, 9th Annual North American Welding Research Conference, Columbus, OH, October, 1993.

25. "NEMA, EPA Develop Environmental Release Estimates for Welding", Welding Design & Fabrication, September 1993, p. 12.

26. IT Corporation, Development of Environmental Release Estimates for Welding Operations, USEPA Risk Reduction Engineering Laboratory, 1993.

27. Graham J. Carter, Fume Emissions from Flux Cored Arc Welding of Stainless Steel Using Small Diameter Consumables, The Environment and the Joining Industry - Product Manufacture, Pollution Prevention, and Safety and Health, Proceedings, 9th Annual North American Welding Research Conference, Columbus, OH, October, 1993.

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29. American Welding Society, "Laboratory Method for Measuring Fume Generation Rates for Total Fume Emission of Welding and Allied Processes", ANSI/AWS F1.2-92, April 21, 1992.

30. American Welding Society, "Method for Sampling Airborne Particulates Generated by Welding and Allied Processes", ANSI/AWS F1.1-92, April 21, 1992.

31. Carl R. Weymueller, "How to Protect Welders Working in Close Spaces", Welding Design & Fabrication, August 1992, p. 30 - 32.

32. Paul Cunningham, "Welding with Cast Iron Tables", The Fabricator, November 1992.

33. Laurie Reding, "Controlling Welding Fume: A Design Approach", Welding Journal, September 1992, p. 61 -64.

34. S. Driscoll, P. Suckling, "Airborne Emissions in Gas Shielded Welding", Welding and Metal Fabrication, Vol. 60, June 1992, p. 227 - 229.

35. Kyle Steenland, Jay Beaumont, Larry Elliot, "Lung Cancer in Mild Steel Welders", American Journal of Epidemiology, Vol.133, No. 3, 1991, p. 220 -229.

36. Steven J. Sferlazza and William S. Beckett, "The Respiratory Health of Welders", Am. Rev. Respir. Dis., Revised January 28, 1991, p. 1134 -1148.

37. John F. Rekus, "Strike an Arc", Occupational Health & Safety, October 1991, p. 24.

38. American Welding Society, "Guide for Welding Fume Control", ANSI/AWS F3.1-89, June 12, 1989.

39. Carl R. Weymueller, "OSHA Rules Aim to Clear the Air", Welding Design & Fabrication, December 1989, p. 33 - 36.

40. Paul Sampara, Control of Exposure to Welding Fumes and Gases, Canadian Center for Occupational Health and Safety, May 1985.

3.0 Welding Fume Study Questionnaire

DynCorp developed and distributed a questionnaire to 30 shipyards and shipyard related industries. Shipyards were selected from Panel SP-7 members and Center for Advanced Ship Repair and Maintenance (CASRM) members. A total of 15 questionnaires were completed and returned to DynCorp from the shipyards listed below:

1. Portsmouth Naval Shipyard
2. Metro Machine Corporation
3. Marine Hydraulics
4. Holmes Brothers Enterprises
5. Bath Iron Works
6. National Steel & Shipbuilding
7. Kerney Service Group
8. Avondale Industries, Incorporated
9. Puget Sound Naval Shipyard
10. Technico Corporation
11. Newport News Shipbuilding
12. Alabama Shipyard
13. Atlantic Marine, Incorporated
14. Electric Boat Corporation
15. Lake Shore, Incorporated

Information received from the questionnaires was entered into an electronic database DynCorp developed based on Microsoft Access software. Nine of the shipyards which responded expressed interest in additional participation in the Welding Fume Study.

A printout of the Welding Fume Questionnaire issued and a printout of the questionnaire database is presented in Attachment A.

4.0 Regulatory Compliance:

DynCorp contacted the Occupational Safety & Health Administration (OSHA), the National Institute for Occupational Safety & Health (NIOSH), the Environmental Protection Agency (EPA) and various state agencies to determine the current regulatory status for chromium, nickel and manganese.

Due to the complexity of the issue and the political climate, OSHA did not issue a draft standard for changes to hexavalent chromium worker exposure levels in October, 1996, as anticipated. The current opinion expressed by members of the OSHA Work Group on Hexavalent Chromium indicate that a Draft Standard for comment is likely to be released in October, 1998. It is anticipated that the Final Rule will be published in 2000, and industry compliance will be required within one to three years of release of the Final Rule.

5.0 Conclusion:

The Information Search included an examination of the current technology available to reduce worker exposure to welding fumes. DynCorp did not discover any significant changes in the design and application of welding fume engineering controls over the past five years.

Although shipyard employers have shown a consistent trend toward improving the conditions of the work environment to enhance worker safety and comfort, compliance with the current fume exposure limits for hexavalent chromium, nickel and manganese provide little economic incentive for employers to make process changes and implement control systems to further reduce fume levels to the exceptionally low levels that are anticipated in the revised OSHA standard. Consequently, welding equipment manufacturers have had little incentive to perform the research and development necessary to develop better control measures for welding fumes.

Task 1

Attachment A

WELDING FUME STUDY QUESTIONNAIRE

Shipyard:________________________________
Date:___________________________________
Name:__________________________________
Department:____________________________
Phone #:________________________________

DynCorp is conducting a Welding Fume Study for the National Shipbuilding Research Program (NSRP) SP-7 Committee. The purpose of this study is to (1) collect information, (2) evaluate welding processes, and (3) make recommendations for process improvements to reduce worker exposure to chromium, nickel and manganese.

As part of Task 1, Information Search, we are contacting several shipyards to establish a baseline of technical information to ensure that later process evaluations meet the current needs of the shipbuilding industry. Please take a moment to complete the attached survey and return it to Brad Christ at DynCorp **before February 7, 1997**. If you have any questions, please call Brad at (703) 264-8630. Thank you for your assistance.

1. Which welding processes are used in the shipyard?:
   _____ Shielded metal arc welding
   _____ Gas metal arc welding
   _____ Gas tungsten arc welding
   _____ Flux cored arc welding
   _____ Submerged arc welding
   _____ Others (please list)

2. Does shipyard conduct breathing zone air monitoring for exposure to welding fumes?
   YES_____ NO_____

3. Has air monitoring for chromium (Cr) or manganese (Mn) or nickel (Ni) been conducted?
   YES_____ NO_____

4. Are the shipyard air monitoring records available for DynCorp to review?
   YES_____ NO_____

5. Are you aware of any recent (1995-1997) changes by local, state or federal regulatory agencies or professional association regarding occupational exposure to Cr, Mn, or Ni?
   YES_____ NO_____

6. Do shipyard standard operating procedures specify engineering controls for the ventilation of welding areas?
   YES_____ NO_____

7. What control measures are used at the shipyard to control worker exposures to welding fumes?
   _____ Exhaust ventilation
   _____ Isolation
   _____ Robotics
   _____ Others (please list)

8. What type of respiratory protection is used by welders?

_____ Half face, HEPA cartridges
_____ Full face, HEPA cartridges
_____ Supplied air line
_____ Others (please list)

9. Are any new types of technology being employed in your shipyard to control worker exposures to welding fumes?
Examples:____

____

____

10. Can you suggest modifications to existing welding processes to reduce worker exposures to fumes?
Examples:____

____

____

11. Has OSHA ever cited the shipyard for worker exposures to welding fumes?
YES_____ NO_____

12. What type of worker training is provided to welders regarding welding fumes?
_____ In house, 1 day or less
_____ In house, more than one day
_____ Outside training, 1 day or less
_____ Outside training, more than one day

13. Is access to welding areas regulated?
YES_____ NO_____

14. Are there specific disposal requirements for waste generated during welding operations?
YES_____ NO_____
If yes, is waste: HAZARDOUS_____ NONHAZARDOUS_____

15. Would your shipyard like to participate in this project?
YES_____ NO_____

Please return this form to:

DynCorp
Attention: Brad Christ
2000 Edmund Halley Drive
Reston, VA 20191
Fax: (703) 264-9210

Shipyard:	Date:	Name:	Department:	Phone	Shield	GMAW	GTAW)	FCAW	Submerge
Portsmouth Naval	01/15/1997	Harold Long	Code 138	(207) 438-2652	Yes	Yes	Yes	Yes	No
Metro Machine Corp.	01/21/1997	William E. Pope	Vice President	(757) 494-0406	Yes	Yes	Yes	Yes	No
Marine Hydraulics	01/16/1997	Stephen M. Beary	Welding	(757) 545-6400	Yes	Yes	Yes	Yes	No
Holmes Brothers Ent., Inc.	01/02/1997	Charles Nash, Jr.	Q/A - Safety	(757) 488-6868	Yes	Yes	Yes	Yes	No
Bath Iron Works	01/02/1997	Ronald A. Lessard	Safety & Health Ops	(207) 442-1638	Yes	Yes	Yes	Yes	Yes
Nat. Steel & Shipbuilding	02/17/1996	Mike Sullivan	Welding Engineering	(619) 544-8581	Yes	Yes	Yes	Yes	Yes
Kerney Service Group	02/21/1996	John Adams	Administration	(757) 622-4400	Yes	Yes	Yes	No	No
Avondale Industries, Inc.	01/13/1997	Martin Summers	Safety	(504) 436-5384	Yes	Yes	Yes	Yes	Yes
Puget Sound Naval	01/08/1997	Steve Nelsen	Welding Engineering C1138	(360) 476-2675	Yes	Yes	Yes	Yes	Yes
Tecnico Corporation	01/16/1997	Joe Kucinski	Safety	(757) 545-4013	Yes	Yes	Yes	Yes	No
Newport News Shipbuilding	01/16/1997	J. M. Sawhill, Jr.	Welding Engineering	(757) 380-7421	Yes	Yes	Yes	Yes	Yes
Alabama Shipyard	01/29/1997	Anand Ramamurthy	Industrial Engineering	(334) 690-7113	Yes	Yes	No	Yes	Yes
Atlantic Marine, Inc.	01/31/1997	Gerald W. mcCrani	Hull	(334) 690-7897	Yes	No	No	Yes	Yes
Electric Boat Corp.	01/21/1997	Kurt S. Cramer	NSSN Env. Compliance	(860) 433-5650	Yes	Yes	Yes	No	Yes
Lake Shore, Inc.	02/03/1997	Bruce Halverson	Manager - Fabrication	(906) 774-1500	Yes	Yes	Yes	Yes	Yes

1

Other Arc Welding	Air	(Cr)	(Mn)	(Ni)	Records	Regulation	Ventilation	Exhaust	Isolation
Timed stud, oxy-fuel lead bonding, oxy-fuel braze	No	No	No	No	No	Yes	Yes	Yes	No
Electrogas, Arc Stud, Carbon Arc Cutting	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
N/A	No	No	No	No	No	No	Yes	Yes	No
N/A	No	No	No	No	No	No	No	Yes	No
N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stud welding, Plasma cutting	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
N/A	No	No	No	No	No	No	Yes	Yes	No
N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
N/A	No	No	No	No	No	No	Yes	Yes	Yes
Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
N/A	No	No	No	No	No	No	No	Yes	No
N/A	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
Resistance spot, timed arc stud	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Torch brazing	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
	No	No	No	No	No	No	No	No	No

2

Other Measures	Half Face HEPA	Full Face HEPA	Supplied Air Line	Other Protection	New Technology
Containments & air-fed hoods	Yes	Yes	Yes	N/A	No
N/A	Yes	No	No	N/A	No
N/A	Yes	Yes	Yes	N/A	No
Respirators	Yes	No	No	N/A	No
N/A	Yes	No	No	N/A	No
Natural ventilation	Yes	No	No	3M 6000 Series	No
N/A	Yes	Yes	No	N/A	No
N/A	Yes	No	No	N/A	No
Mechanized welding	Yes	Yes	Yes	N/A	No
N/A	Yes	No	No	N/A	Yes
Yes	Yes	No	Yes	N/A	Yes
N/A	Yes	No	No	N/A	Yes
Blowers	Yes	No	No	N/A	No
N/A	Yes	Yes	Yes	N/A	Yes
N/A	Yes	Yes	Yes	Disposable 3M 9920	Yes
	Yes	No	No		No

3

Example:	Suggest Modifications	OSHA Citations	Training IH <1 Day	Training IH >1 Day
N/A	N/A	No	Yes	No
N/A	N/A	No	Yes	No
N/A	N/A	No	Yes	No
N/A	N/A	No	No	No
N/A	N/A	No	No	Yes
N/A	N/A	No	Yes	No
N/A	N/A	No	Yes	No
N/A	N/A	No	No	Yes
N/A	N/A	Yes	Yes	No
Low emission electrode	N/A	No	Yes	No
Mechanized, Robotic	Optimize process based on carcinogen levels	No	Yes	No
Fume extraction units	Robotics/Fume extraction	No	Yes	No
N/A	N/A	No	Yes	No
MIG fume extraction torch	Minimize SMAW, substitute GMAW, lo-fume	Yes	Yes	No
Fume extraction guns	Lighten extraction guns, reformulate FCWA wires	No	No	Yes
		No	No	No

Training OS < 1	Training OS > 1 Day	Restricted Access	Disposal	Hazardous Waste	Participation
No	No	No	Yes	No	Yes
No	No	No	No	No	No
No	No	No	No	No	No
No	No	No	No	No	No
No	No	No	No	No	Yes
No	No	No	No	No	Yes
No	No	No	No	No	No
No	No	No	No	No	Yes
No	No	No	Yes	No	Yes
No	No	No	No	No	No
No	No	No	No	No	Yes
No	No	No	No	No	Yes
No	No	Yes	No	No	No
No	No	No	Yes	No	Yes
No	No	Yes	Yes	No	Yes
No	No	No	No	No	No

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Impact of Recent and Anticipated Changes in Airborne Emission Exposure Limits on Shipyard Workers
Author: The Navy Joining Center and A Navy/Industry Task Group
Date: March 1996
Source: The National Shipbuilding Research Program

Abstract:

Report addresses the anticipated future reductions in OSHA and ACGIH worker exposure limits for nickel, manganese and hexavalent chromium. Shipyard operations, materials and processes which are expected to be most impacted are identified, current worker exposure levels are examined, the technical and economic impact of the anticipated reductions are explored, and future actions which may be necessary to comply the anticipated reductions are discussed.

Specific shipyard related tasks which have the potential for exposure to Cr(VI), Ni and Mn are identified. The study concludes that the anticipated reduction in the Cr(VI) would have a much greater impact than the anticipated reductions in Ni and Mn. A PEL of 5.0 ug/m3 to 10.0 ug/m3 is noted as a more feasible reduction.

The report estimates that 18,000 shipyard workers would be affected if the PEL were decreased to 0.5 ug/m3, but that only 3,200 shipyard workers would be affected if the PEL were decreased to 5.0 mg/m3. The estimated annual cost for a Navy facility to comply with a PEL of 0.5 ug/m3 was $46,000,000, a PEL of PEL of 5.0 ug.m3 was $5,000,000, and a PEL of 10.0 ug/m3 was $2,000,000.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Workshop Session 1996, Chromium (VI) Update: Impact of OSHA and Navy Initiatives Hexavalent Chromium Exposure Evaluation
Author: John Bishop
Date: 1996
Source: Navy Environmental Health Center

Abstract:

Handout provided by John Bishop at the 37th Navy Occupational Health and Preventative Medicine Workshop detailing history of anticipated reduction of OSHA permissible exposure limit for hexavalent chromium. The objectives of the Navy/Industry Task Group project are outlined. Recommendation made for additional air sample data collection using the new OSHA 215 method.

Operations and occupations with a potential for hexavalent chromium exposure are identified. Hexavalent chromium air sample results from the Industrial Hygiene Data Capture database at Navy Environmental Health Center (NAVENVIRHLTHCEN) are presented as well as requirements for respiratory protection for several potential PELs.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Health Standard for Manganese
Author: John Bishop
Date: June, 1996
Source: Navy Environmental Health Center

Abstract:

Report generated at the request of the Deputy Under Secretary of Defense for an evaluation of manganese exposures to Navy workers and an assessment of the impact of a reduced manganese standard. The report estimated 23,107 Navy employees were potentially exposed to manganese. Engineering controls used to reduce worker exposures to manganese were summarized. No cases of manganese toxicity were discovered in Navy workers using current Navy medical surveillance methods. Additional epidemiological data study recommended. Economic impact estimates made which included one time cost and fixed annual cost.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Impact of Anticipated OSHA Hexavalent Chromium Worker Exposure Standard On Navy Manufacturing And Repair Operations
Author: Navy/Industry Task Group
Date: October 1995
Source: Navy Sea System Command

Abstract:

The Navy Sea Systems Command coordinated a Navy/Industry Task Group to assess the technical and economic impact of the anticipated OSHA reductions in the permissible exposure limits (PEL) for hexavalent chromium [Cr(VI)]. The existing PEL of 100 ug/m3 is expected to be reduced to between 0.5 ug/m3 and 5.0 ug/m3.

The Navy/Industry Task Group identified operations where worker exposures to Cr(VI) were expected, determined current worker exposure levels using OSHA 215 method, estimated the economic impact of the anticipated standard, and identified actions necessary to comply with anticipated standard.

The Navy/Industry Task Group concluded that the anticipated reduction in the Cr(VI) PEL would have a significant technical and economic impact on shipyards and shipyard related industries. A more feasible level would be 5.0 ug/m3 to 10.0 ug/m3.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "The Particle Size Distribution, Density, and Specific Surface Area of Welding Fumes from SMAW and GMAW Mild and Stainless Steel Consumables"
Author: Paul Hewett
Date: February 1995
Source: American Industrial Hygiene Association Journal

Abstract:

Particle size distributions were measured for fumes from mild steel (MS) and stainless steel (SS); shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) consumables. Up to six samples of each type of fume were collected in a test chamber using a micro-orifice uniform deposit (cascade) impactor. Bulk samples were collected for bulk fume density and specific surface area analysis. Additional impactor samples were collected using polycarbonate substrates and analyzed for elemental content. The parameters of the underlying mass distributions were estimated using a nonlinear least squares analysis method that fits a smooth curve to the mass fraction distribution histograms of all samples for each type of fume. The mass distributions for all four consumables were unimodal and well described by a lognormal distribution; with the exception of the GMAW-MS and GMAW-SS comparison, they were statistically different. The estimated mass distribution geometric means for the SMAW-MS and SMAW-SS consumables were 0.59 and 0.46 um aerodynamic equivalent diameter (AED), respectively, and 0.25 um AED for both the GMAW-MS and the GMAW-SS consumables. The bulk fume densities and specific surface areas were similar for the SMAW-MS and SMAW-SS consumables and for the GMAW-MS and GMAW-SS consumables, but differed between SMAW and GMAW. The distribution of metals was similar to the mass distributions. Particle size distributions and physical properties of the fumes were considerably different when categorized by welding method. Within each welding method there was little difference between MS and SS fumes.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title:	"Estimation of Regional Pulmonary Deposition and Exposure for Fumes from SMAW and GMAW Mild and Stainless Steel Consumables"
Author:	Paul Hewett
Date:	February 1995
Source:	American Industrial Hygiene Association Journal

Abstract:

The particle size distributions and bulk fume densities for mild steel and stainless steel welding fumes generated using two welding processes (shielded metal arc welding [SMAW] and gas metal arc welding [GMAW] were used in mathematical modes to estimate regional pulmonary deposition (the fraction of each fume expected to deposit in each region of the pulmonary system) and regional pulmonary exposure (the fraction of each fume expected to penetrate each pulmonary region and would be collected by a particle size-selective sampling device). Total lung deposition for GMAW fumes was estimated at 60% greater than that of SMAW fumes. Considering both the potential for deposition and the fume specific surface areas, it is likely that for equal exposure concentrations GMAW fumes deliver nearly three times the particle surface area to the lungs as SMAW fumes. This leads to the hypothesis that exposure to GMAW fumes constitutes a greater pulmonary hazard than equal exposure to SMAW fumes. The implications of this hypothesis regarding the design of future health studies of welders is discussed.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Guide for Selection of Fume Exhausters"
Author: Walter F. Emerson
Date: February 1995
Source: Welding design & Fabrication

Abstract:

The two categories of fume exhausters are high vacuum/low volume and low vacuum/high volume. Energy costs and maintenance issues of each category must be considered prior to selection. Selection of the correct type of fume exhauster depends upon the amount and type of welding to be performed. Low vacuum fume exhausters work well for small shops with few work stations. High vacuum units cost effective for shops with many workstations. High vacuum equipment not effective in cases where weldment smokes after arc extinguishes. It is necessary to factor in proper balance of the existing air handling system when considering installation of a fume exhaust system. Once the fumes are captured at the source, there are a variety of filter mechanisms available to capture the fumes. Increased productivity and reduced operating demand of the general ventilation system are the results of a properly designed and installed fume extraction system.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Gas Metal Arc Welding Fume Generation Using Pulsed Current"
Author: Harvey Castner
Date: February 1995
Source: Welding Journal

Abstract:

While the fume generation rate of gas metal arc welding (GMAW) is lower than some other arc welding processes, the further reduction of welding fumes is of interest to companies using GMAW. Several researchers have reported lower fume generation rates for pulsed current welding compared to steady current. However, the range of welding parameters where these reduced fume levels can be expected has not been well documented.

This paper describes a study of the effects of pulsed welding current on the amount of welding fume and ozone produced during GMAW using a range of welding parameters. Fume generation rates were measured for steady current and pulsed current GMAW of mild steel using copper-coated ER70S-3 welding wire and 95% Ar-5% CO2 and 85% Ar-15% CO2 shielding gases. The amount of fume generated during welding was determined by drawing fume through a fiberglass filter using the standard procedures contained in ANSI/AWS F1.2.

Results of these measurements show that pulsed welding current can reduce fume generation rates compared to steady current. There is a range of welding voltage that produces the minimum fume generation rate for each wire feed speed with both pulsed and steady current. The data also show that using pulsed current does not guarantee lower fume generation compared to steady current. Welding parameters must be correctly controlled if pulsed current is to be used to reduce fume levels. Fillet welds were made to demonstrate that the pulsed current welding parameters that reduce fume also produce acceptable welds.

No significant difference was found in the chemical composition of fumes from pulsed current compared to steady current. Fumes generated by both types of current are mixtures of iron, manganese and silicone oxides. Measurements of ozone generation rates show that the pulsed current welding parameters that reduce fume also increase ozone generation compared to steady current welding.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "New Generation of Cored Wires Creates Less Fume and Spatter"
Author: Stanley E. Ferree
Date: December 1995
Source: Welding Journal

Abstract:

A new generation of flux cored wires has been developed which produce 20% to 75% less fumes than previous versions, with similar reductions in spatter emissions. American Welding Society specifications do not provide a description of the fume emission rates so welding fabricators must rely on cored wire manufacturers for selection. Reducing the more volatile core ingredients allows the new generation of cored wires to reduce fume emissions and an additional benefit is reduced spatter emissions. Reduced spatter means less clean-up time, less downtime and fewer body burns. Higher current levels produce more fumes, but the fume generation rate may be offset by the reduction in joint time. Voltage, operator factor, shielding gas and base plate type also contribute to fume generation rates.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: “Welding Could Become an OSHA Priority”
Author: Hugh K. Webster
Date: February 1995
Source: Welding Journal

Abstract:

The National Advisory Committee on Occupational Safety and Health (NACOSH) has recommended to the Occupational Safety and Health Administration (OSHA) that welding, cutting and brazing, as well as welding fumes be a “high priority” on their agenda. NACOSH is comprised of industry, labor, academia, and state government representatives working together to improve worker safety. NACOSH works closely with OSHA.

OSHA has conducted a comprehensive prioritization effort, and has solicited comments from the public, including public hearings. In late 1994, after compiling the information from the hearings, among other things, NACOSH included welding in its top 14 recommended areas for OSHA to be most concerned with. NACOSH can not make any policy changes, only recommendations

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Fume-Extractor Guns Clean the Air"
Author: Not listed
Date: February 1995
Source: Welding Design & Fabrication

Abstract:

Cleveland Range, Euclid, Ohio, replaced the individual electrostatic ventilation units with a Lincoln Electric central-exhaust system and associated equipment. Cleveland Range noted a reduction in visible welding fumes and found the system to be low maintenance. Weld porosity due to fan drafts were reduced. Once welders became used to the fume extraction gun, they preferred them to the standard GMAW gun. A welding supervisor indicated that the fume extractor guns also improved employee morale.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Respirator Selection for Metal-Fabricating Shops"
Author: Terry G. Eichman
Date: April 1995
Source: Welding Design & Fabrication

Abstract:

Welders face respiratory hazards from fumes, dusts, and gases. The concentration of airborne contaminants must be measured to determine worker exposure levels and determine the type of respirator that can provide an acceptable protection level in order to comply with the OSHA standard for respiratory protection (29 CFR, 1910.134). The standard says employers must use engineering controls to eliminate contaminants, but in cases where engineering controls are not feasible, employers must provide respiratory protection.

Respirators are grouped into two categories: positive pressure and negative pressure. Positive pressure respirators deliver air from a powered source. Negative pressure respirators remove contaminants using filters that the worker breathes through. There are a wide variety of respirator types available.

Workers must be properly trained and fitted prior to using a respirator. The employer must establish a written standard operating procedure for respirator selection and use. Respirators must be properly maintained and stored.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Fume Control System Helps Students Breathe Easier"
Author: Not listed
Date: June 1995
Source: Welding Journal

Abstract:

The Hobart Institute of Welding Technology, Troy, Ohio, replaced their old welding fume collection and exhaust system with a central filtration system installed by Hawthorne Systems, Incorporated. The old system was replaced because it required a great deal of maintenance, it was not cost effective, and the overall draw of the old system was not sufficient. An engineering firm was contracted to make preliminary recommendations. Bids for the new fume collection system were solicited from 10 companies.

The Hawthorne system removes the fumes at the booths, filters the air, and returns the cleaned air to the building. Two large dust collectors serve a total of 84 welding booths and manual welding stations. The collection hoods and duct work were custom tailored in each booth for the type and position of welding planned for that booth. The recirculation of air afforded by the central filtration system is expected to provide a $37,000 per year fuel savings cost.

The cost of the system was $700,000. The contract was awarded in September, 1994, and the installation was completed on January 2, 1995. The school remained open all but two weeks during the installation and the project was completed on schedule.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Welding Fume - Control and Guidance"
Author: P. J. Blakeley
Date: October 1995
Source: Welding and Metal Fabrication

Abstract:

All forms of arc welding produce fumes that may be hazardous to health. The concentration of fume depends upon working materials and the type of process being used. The particles produced (fume) can remain airborne for extended periods of time, therefore it is necessary to remove the fume from the work area as quickly as possible. To effectively remove the fume, position extraction ducts as close as possible to the point of welding. The most efficient method is to use a centralized extraction unit that can service many different ports throughout the shop. The system should vent the filtered air outside, reducing the chance of pollutant buildup in the work center. When this is not feasible, a portable system may be used. This system requires more operator maintenance and usually returns the filtered air into the work center. Although the fume content of the filtered air is reduced, the air could contain gases or finer particles that were not filtered out. In addition to the extraction devices, it may be necessary to provide clean air to the welder's protective helmet when elevated levels of fume are produced, or when working in confined spaces.

The welders in the shop should be trained to position themselves sensibly when fume is generated. It must be ensured the general atmosphere of the workshop is ventilated properly and that the proper extraction device is used to minimize the amount of fume introduced to the work area.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Take a look at Fume Extracting Welding Guns"
Author: Andrew Cullison
Date: September 1994
Source: Welding Journal

Abstract:

Welding fume extraction guns are becoming lighter and less awkward to use. Exhaust hoses are now lighter, more flexible and made of a higher quality materials. Fume extraction guns act like a vacuum cleaner with a built in spark arrestor and are especially effective in confined areas where auxiliary ventilation is difficult to establish. The vacuum system helps cool the gun. There are more than 20 models available on the market with a wide variety of features. Care must be taken to establish the proper setup and technique to maximize fume recovery. Extraction efficiency is greatest in the flat welding position. Fume extraction guns require additional maintenance over standard guns. Efficiency is typically achieved with a minimum flow rate of 70 ft3/min at the extraction nozzle. High amperage units are under development for use with robotic systems.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title:	"Exposure to Solid Aerosols During Regular MMA Welding and Grinding Operations on Stainless Steel"
Authors:	Jan T. Karlson, Torgrim Torgrimsen, Sverre Langard
Date:	December 1994
Source:	American Industrial Hygiene Association Journal

Abstract:

Tests of air concentrations of solid aerosols during manual metal arc (MMA) welding on stainless steel were carried out at three working sites. In addition to a detailed description of the work situation, samples of welding fume were collected from both the breathing zone and the general air. Air concentrations of total solid aerosols were determined gravimetrically. Total amounts of metal compounds [i.e., nickel (Ni), chromium (Cr), iron, and manganese] and water-soluble hexavalent chromium (CrVI), were determined. The mean fume concentrations during MMA welding were 5.4 mg/m3 inside a ship section, 3.0 mg/m3 at an offshore module, and 2.0 mg/m3 in welding shops. The highest concentrations of CrVI were found during MMA welding inside the ship section, with a mean concentration of 140 ug/m3 (range 4-640 ug/m3). CrVI comprised about 50% of the total Cr by weight. Though the base material contained approximately 20% Cr and 10% Ni, the Cr and Ni contents (ug/mg welding fumes) varied greatly among the different welding sites. Grinding generated a mean concentration of 11 mg/m3, of which Cr was about 10% of the total solid aerosol.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Shielding Gas, Wire Type Have Drastic Affect on Fume Emissions"
Author: Not Listed
Date: July 1994
Source: Welding Design and Fabrication

Abstract:

BOC Limited, London, England reported that gas-tungsten-arc welding (GTAW) produced less than 10% of the fumes generated by gas-metal-arc welding (GMAW). GMAW generated the most fumes in the test during globular transfer. When the current passes 200 amps, fumes decrease.

British researchers measured Fume Formation Rate (FFR) for the following welding operations:
A. Gas-metal-arc-welding (GMAW)
B. Gas-tungsten-arc-welding (GTAW)
C. Metal-cored-arc-welding (METAL-CORED)
D. Flux-cored-arc-welding (FCAW)

The measurements were taken from mild steel and stainless steel welding operations. Fumes from GTAW were insignificant.

When used in conjunction with mild-steel, solid wire and argon containing shielding gases, the FFR increased most rapidly between 180-200 amps and begins to decrease from 200-240 amps. Carbon dioxide yields twice as much fume.

The FFR for flux-cored wires (basic and rutile) was between 2 and 3 times higher than for solid wire. Increased carbon dioxide content of the shielding gas increases the amount of fume generated.

Type ER309L wire was chosen by researchers for tests on stainless steel because it had the highest chromium emission, and represented the worst health risk. High-helium gas was used with the stainless steel solid wire because it produced more fume than argon-based gases. Fumes at high and low levels of amperage contained elevated amounts of chromium. Short-circuit transfer created more hexavalent chromium.

The type ER309LT rutile-flux-cored wire yielded lower chromium levels than the solid wire, but could generate up to four times more hexavalent chromium with argon-based gases.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "High-Vacuum Extraction of Welding Fumes Within the Shipbuilding Industry"
Author: Jorgen E. Rasmussen
Date: 1994
Source: Svetsaren

Abstract:

Increased competition has led to increased welding production being performed indoors. Increased fume emissions have led to increasingly deteriorating working conditions for shipbuilders in recent years. For this reason builders are now using high-vacuum systems operating at 20 kPa to secure the correct extraction capacity to help evacuate respiratory hazards in the work area. These systems may be stationary for internal work areas, or mobile units which can be used internally or externally on locations such as the docks, and inside confined spaces in the ship itself.

The most popular system is a small suction nozzle with a magnet base, or a torch with integrated extraction connected to a small flexible hose about 45-50 mm wide. The length of the hoses can be up to 30 meters without sacrificing effectiveness. Most systems have been designed to work in the most extreme conditions without mechanical failure.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: “Smoke Won't Get in Your Eyes in This Welding Lab”
Author: Mary Ruth Johnson
Date: September 1994
Source: Welding Journal

Abstract:

The ventilation system for the Norfolk Southern Railroad Training Center could not keep up with the generation of fumes. Instructors and students were forced to wear respirators at all times while in the welding lab, which impaired the learning process.

Norfolk Southern decided to build a new welding lab with welding booths designed to create laminar air flow from front to rear and away from the students. The ventilation system requirements were a primary consideration during the design phase of the new facility. The welding lab contains 22 welding stations and 11 cutting stations.

The welding booths are manufactured by Environmental Clear Air Company. Each booth is rated at 8,000 cubic feet per minute. Each cutting table is rated at 1,500 cubic feet per minute with a downdraft velocity of 375 cubic feet per minute. The filtering system consists of 12 cellulose cartridge filters and are rated for an efficiency of 99.9% at 0.5 microns. Norfolk Southern Industrial Hygiene Department tests show the air being recirculated back from the filtration system is cleaner than the outside air.

The Senior Training Officer at the facility expressed satisfaction with the performance of the system.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: “OSHA Readies Itself for More Action”
Author: Hugh K. Webster
Date: Not Listed
Source: Welding Journal

Abstract:

OSHA reported to be considering a reduction of the PEL for hexavalent chromium from 100 micrograms per cubic meter to 0.5 to 5 micrograms per cubic meter. OSHA indicated that excessive exposure to hexavalent chromium may increase the risk of lung cancer, and contribute to bronchial asthma, skin ulcers, and other health conditions.

OSHA intended to propose a rule for general industry, agriculture and maritime work, with a separate standard for the construction industry. The OSHA Advisory Committee on Construction Safety and Health formed a workgroup to study the construction industry. The work group was to determine whether certain types of work would be affected by a reduction in the PEL. The standards were tentatively scheduled to be released in May, 1995.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: “A Welder’s Guide to Respiratory Protection”
Author: Craig E. Colton
Date: September 1994
Source: Welding Journal

Abstract:

The article provides a basic overview of the requirements of a respiratory protection program. It covers types of hazards, steps necessary to identify them, the effects of hazards on the workers, how to select the appropriate respiratory protection, training maintenance, records keeping, as well as spelling out the four basic steps for compliance with OSHA. It speaks briefly of “welding fume fever”, a flu-like illness that is repeatedly suffered by some welders. Symptoms include fever, chills, sore throat and nausea. The illness is caused from inhalation of the fine, sometimes invisible particles that are generated as a result of the welding process. The illness may occur within 24 hours of the exposure to the particles, and is usually short-lived. However, repeated illness may leave the worker with an increased risk for lung disease, abdominal pain, and / or kidney damage.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “Coping with Welding Hazards”
Author: Not Listed
Date: April 1994
Source: <u>Welding and Metal Fabrication</u>

<u>Abstract:</u>

There are two types of fume produced as a by-product of welding operations; invisible gaseous fume and visible particulate fume. Both are detrimental to the workers health when inhaled. Gaseous fumes are produced by the action of arc plasma on shielding gases and surrounding air, producing ozone. Particulate fumes are produced when the heat of the arc volatizes small quantities of metal and consumables. The amount of fume is dependent on the welding process, current, consumables and the metal being welded.

The best way to deal with the hazard is to extract the contaminants at the source. Other ways to reduce the risk of exposure is shielding the gas to produce fewer fumes, set welding controls correctly, and adopting a comfortable welding position.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “Measurements of GMAW Fume Generation Rates Using Pulsed Welding Current ”
Author: Harvey R. Castner
Date: October 1993
Source: 9th Annual North American Welding Research Conference

Abstract:

This paper describes studies of fume generation rates for pulsed current gas metal arc welding (GMAW) conducted at Edison welding Institute. Fume generation rates were measured for steady current and pulsed current GMAW of mild steel, stainless steel, a nickel alloy and aluminum alloys.

Results show that pulsed welding current can reduce fume generation rates compared to steady current for many welding procedures. The use of pulsed current does not guarantee lower fume generation rate compared to steady current. There is a specific range of welding voltage that produces the minimum fume generation rate for each wire feed speed with both pulsed and steady current. Welding parameters must be correctly controlled if pulsed current is to be used to reduce fume levels.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "Development of Environmental Release Estimates for Welding Operations"
Author: Kenneth L. Brown
Date: October 1993
Source: The Lincoln Electric Company

Abstract:

Description of findings of welding tests and sampling conducted by the IT Corporation at the Lincoln Electric Company in Cleveland, Ohio in conjunction with the National Electric Manufacturers Association (NEMA). The parameters used in the tests were the manufacturers' recommendations or those in common use by fabricators. These parameters included current, voltage, polarity, electrode extension, electrode angle, type of shielding gas, and weld travel speed.

The article includes tables for use in the estimation of toxic emissions from welding operations. Information provided included fume generated per amount of electrode used, metal concentration in slag of commonly used electrodes, metal concentration in fume of commonly used electrodes, slag generated per amount of electrode consumed, average chemical-specific emission factors (fume) and average chemical-specific release factors (slag).

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: "NEMA, EPA Develop Environmental Release Estimates for Welding"
Author: Not Listed
Date: September 1993
Source: Welding Design and Fabrication

Abstract:

The National Electrical Manufacturers Association (NEMA) and the Environmental Protection Agency (EPA) have developed estimates for amounts of chemicals released during welding to help companies comply with SARA, Title III, Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986.

Included in the article is a chart listing the average metal-emission factors for fume. Information is listed for 11 different electrode classes and for nine different metals.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Development of Environmental Release Estimates for Welding Operations
Author: IT Corporation
Date: 1993
Source: USEPA Risk Reduction Engineering Laboratory

Abstract:

The IT Corporation conducted a study of environmental release factors for metal welding operations to provide an estimate of emissions of selected metals as required under the Superfund Amendments and Reauthorization Act (SARA), Title III, Section 313. Measurement data was collected at the Lincoln Electric Company facility in Ohio. Lincoln provided the equipment, materials and welders. The report was submitted to the USEPA.

Flux-cored electrodes, solid wire with gas shielding, and manual electrodes were all studied. Objectives were to determine the quantity and composition of the fumes and dust from the 10 most commonly used electrodes and to develop emission factor release estimates for the electrodes.

Welding fumes and slag were sampled. Metals analysis was performed for aluminum, Copper, Chromium, Cobalt, Nickel, Manganese, Vanadium, Barium, and Zinc and the results were used to generate emission factor release estimates.

LITERATURE REVIEW FOR WELDING FUME STUDY
TASK 1

Title: Fume Emission from Flux-Cored Arc Welding of Stainless Steel Using Small Diameter Consumables
Author: Graham J. Carter
Date: October 1993
Source: 9th Annual North American Welding Research Conference

Abstract:

There has been steady market growth for small diameter flux cored wires, but concern has arisen in regard to high fume emission rates. Commercially available flux cored wires for stainless steel were examined to determine the effects of changing welding parameters, shielding gas composition, and flow rates on the fume emission rate and composition. Work was performed at The Welding Institute.

Flux cored wires with various levels of sodium, potassium, and lithium were examined to determine what effect these compounds had on the generation rate of hexavalent chromium. Measurement were made in a fume box using DC+ polarity, Ar-20% CO2 shielding gas at flow rate of 15 liters per minute, and an electrode extension of 18mm. Voltage selected by optimizing the welding conditions.

It was determined that minimum fume emission rates were associated with lower welding current, an optimized arc voltage, less oxidizing shielding gases, electrode extensions of about 18mm, smaller diameter wires, and the absence of sodium and potassium compounds in the flux.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Testing the Quality of Welders' Air"
Author: Eli Smyrloglou
Date: December 1993
Source: Welding Design & Fabrication

Abstract:

A study conducted by J. W. Goller and N. W. Paik, published in the Journal of Industrial Hygiene Association, found that the concentration of iron oxide outside a welder's helmet is 1.41 to 2.75 times greater than the concentration inside the helmet during welding operations. This prompted the Occupational Safety and Health Administration (OSHA) to mandate that air inside welder's helmets must be monitored periodically to ensure that the air is acceptable by current regulations.

The air sampling requires that the sample be taken in the workers' breathing zone, indicating the workers' inhalation hazard.. This is accomplished by placing a portable pump on the welder's body. The pump draws contaminated air at a measured volumetric rate through one of many types of sampling media. Sampling media choices are: a cassette (for aerosols and dusts), and / or glass tube (for vapors and gases). When analyzed by an accredited laboratory, the media will indicate the contaminant content in the air. An absorbent tube (for vapors and gases) and / or real time instruments may also be used to indicate levels of contaminants in the air with almost instant results. The last two methods are thought to be less accurate, or representative, of a worker's exposure than the others are.

The industrial hygienist may use either the material safety data sheets (MSDS), or contact the manufacturer of the electrodes and base materials to find the composition of the parts or materials consumed in the welding process. This will allow the hygienist to verify that all possible contaminants are being sampled for.

Sampling should be performed on a representative sample of workers at least once per year. New surveys should be conducted after making changes in the welding process or the materials consumed during the process. New evaluations should be performed if the welding location or ventilation system has changed.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Laboratory Method for Measuring Fume Generation Rates for Total Fume Emission of Welding and Allied Processes"
Author: American Welding Society
Date: April 1992
Source: ANSI/AWS F1.2-92

Abstract:

This document outlines a laboratory method for the determination of fume generation rates and total fume emission. A test chamber is used to collect representative fume samples under carefully controlled conditions.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Method for Sampling Airborne Particulates Generated by Welding and Allied Processes"
Author: American Welding Society
Date: April 1992
Source: <u>ANSI/AWS F1.1-92</u>

<u>Abstract:</u>

This document aids the reader in the proper technique for sampling welding fume in the workplace. Emphasis is placed on positioning the sampling device and calibration of the equipment.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "How to Protect Welders Working in Close Spaces."
Author: Carl R. Weymueller
Date: August 1992
Source: Welding Design & Fabrication

Abstract:

Welders and other workers inside confined spaces must be taught how to recognize hazards and what steps are necessary to protect themselves. Natural ventilation is limited in confined spaces, allowing oxygen to be depleted and pollutants to accumulate, much faster than in other atmospheres. The air in these areas must be evacuated and replaced with fresh air to reduce the health hazard. In addition, the atmosphere should be monitored before, during, and after welding to ensure that levels are such that there is no chance for fire, explosion or asphyxiation.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Welding with Cast-Iron Tables"
Author: Paul Cunningham
Date: November 1992
Source: The Fabricator

Abstract:

Cast-iron welding tables have been in wide use since before World War II. Many of these original "T" slot tables and welding platens are still in use today. The welding tables were originally used in shipbuilding, machine shops, and basic fabrication shops. The tables are used for clamping and fixturing welded parts.

With the introduction of the Occupational Safety and Health Administration (OSHA) guidelines in 1992, the push pull style downdraft platen table was implemented. An overhead fan pushes the smoke back toward the table, while the optional ductwork positioned under the platen, paired with an exhaust fan (or air cleaner), pulls the welding emission down through the holes in the platen. This system removes fume or other airborne emissions from the welders' breathing zone.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Controlling Welding Fume: A Design Approach"
Author: Laurie Redding
Date: September 1992
Source: Welding Journal

Abstract:

The Occupational Safety and Health Administration (OSHA) established regulations in 1989 for welding fume and its various components. When the regulations were established in 1989, companies had three methods for compliance: administrative controls, personal controls and engineering controls. Effective December 31, 1992, compliance with OSHA regulations had to be achieved through engineering controls where feasible. Administrative or personal controls were deemed acceptable only when engineering controls are not feasible.

Source capture is the preferred method for engineering control, because it is generally more effective and less expensive. Source capture may either vent to the outside, or connect to a filter system. The first source capture option can be accomplished by using a hood located on the welding gun, an articulated source extraction arm, or a fixed hood. the second option is an articulated source collection arm. The arm provides the employee the option of moving the hood where it is needed.

General ventilation is another way to establish engineering control. This method can be as simple as placing fans strategically around the worker to keep fume out of their breathing zone, exhausting shop air outside and bringing in an adequate amount of make-up air. Or the system could be very complex depending on the requirements of the shop. There are a few drawbacks associated with this method. Since fume is not being captured at the source the worker must be protected from the fume through the use of additional personal protective equipment. Second, more air is required for an effective general ventilation system, which is usually more costly.

There are several options available for filtering welding fume including: electrostatic precipitators, bag filters, and cartridge-type filtration. Electrostatic precipitators are mechanical filters that electrically charge particles, then direct them through a group of oppositely charged collector plates. Bag filters are a barrier-type filter used occasionally for welding operations. Cartridge-type filters have gained popularity in recent years because they contain more filter media in a smaller footprint than bag filters.

All of the above mentioned filters may be used with portable fume collectors, permanent workstation collectors, or central workstation collectors.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “Airborne Emissions in Gas Shielded Welding”
Author: S. Driscoll, P. Suckling
Date: June 1992
Source: Welding and Metal Fabrication

Abstract:

Substances discharged into the air during welding operations usually are categorized as dust, fume, or gases. Solid particles larger than 1 microgram in diameter are usually referred to as dust, and particles smaller than 1 microgram are usually referred to as fume. Due to the large size of the dust, the particles tend to fall in the vicinity of the welding arc and do not enter the breathing zone. Fume, smaller than dust, may remain suspended in the air for long periods of time and may be carried to areas surrounding the work area.

Fume is produced by metal vapor, formed in the welding arc, condensing and oxidizing upon contact with the air. The composition of fume relates directly to that of the consumable. If the filler wire being used contains high concentrations of chromium, silicon or manganese, for example, the fume will be rich in their oxides.

Surface coatings may also contribute to fume emissions. Coatings used to paint, galvanize, enamel or plate usually contain harmful substances, and should be removed prior to any welding operation. When this is not possible, you must ensure that the proper extraction devices are incorporated.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Lung Cancer in Mild Steel Welders"
Author: Kyle Steenland, Jay Beaumont, Larry Elliot
Date: 1991
Source: American Journal of Epidemiology

Abstract:

To investigate lung cancer risk, the authors conducted a historical cohort mortality study of 4,459 mill steelworkers who had been employed in three Midwestern plants which manufactured heavy equipment. Follow-up began in the mid-1950s and extended through 1988. All welders had at least 2 years welding experience (average duration, 8.5 years). This cohort had no occupational exposure to asbestos or stainless steel fumes (containing nickel and chromium), two potential confounders in previous welding studies. A comparison population of 4,286 non-welders, all with at least 2 years employment at the same plants, was also studied. Non-welders had never been welders and were allowed to have no more than 90 days employment as painter, foundryman, or machinist. Sampling data collected from 1974 - 1987, indicated that welders were exposed to 6 - 7 mg/m3 of total particulate and 3 - 4 mg/m3 of iron oxide, while non-welders had negligible exposures to welding fumes. When compared to the United States population, both welders and non-welders had elevated rates for lung cancer (standardized mortality ratios (SMRs): welders, SMR = 1.07; non-welders = 1.17), but neither SMR was significantly elevated. Limited smoking data based on a 1985 survey indicated that both welders and non-welders smoked more than the United States population, possibly accounting for part of their elevated lung cancer rates. There was no trend of increased risk for welders with increased duration of exposure. The only other cause of death significantly elevated was emphysema among welders. Nonmalignant respiratory disease was not elevated for welders (SMR = 0.96). When welders were compared with non-welders directly for lung cancer, the rate ratio was 0.90.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: "Respiratory Health of Welders"
Author: Steven J. Sferlazza, William S. Beckett
Date: January 1991
Source: Am. Rev. Respir. Dis.

Abstract:

A detailed review of the pulmonary effects associated with welding. Acute respiratory effects, including metal fume fever, chemical and hypersensitivity pneumonitis, transient and reversible effects on lung function, and chronic respiratory effects, including chronic bronchitis, chronic pulmonary function abnormalities, pneumoconiosis, lung cancer, and occupational asthma, are discussed at length. Proper protection and workplace conditions largely contribute to the specific health effects, severity, and incidence rates of welding associated respiratory disease.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “Strike an Arc”
Author: John F. Rekus
Date: October 1991
Source: Occupational Health & Safety

Abstract:

Description of welding processes and related health effects. Explanation of how fumes are generated during welding and the types of welding fumes. Other health hazards associated with welding including toxic gases, radiation, lead poisoning, and confined spaces. Recommendations for hazard control are inform workers of associated hazards, provide suitable engineering controls and personal protective equipment, and examine existing ventilation controls to determine if they are operating efficiently.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “Guide for Welding Fume Control”
Author: American Welding Society
Date: June 1989
Source: ANSI/AWS F3.1-89

Abstract:

This document introduces the reader to various types of ventilation systems, including dilution and local exhaust, for control of welding fume. It contains health hazard information on air contaminants found in the fume, sample design calculations, and drawings that illustrate ventilation techniques.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: “OSHA Rules Aim to Clear Air”
Author: Carl R. Weymueller
Date: December 1989
Source: Welding Design & Fabrication

Abstract:

The article summarizes welding fume and safety related topics which were presented at a two day seminar, Managing The Welding Environment To Protect Workers, that was put on by the American Welding Society in 1989. Sources of fume generation and control measures are discussed. NIOSH recommendations for lower exposure limits to OSHA are emphasized.

LITERATURE REVIEW FOR WELDING FUME STUDY

TASK 1

Title: Control of Exposure to Welding Fumes and Gases
Author: Paul Sampara
Date: May 1985
Source: Canadian Centre for Occupational Health and Safety

Abstract:

Document summarizes some of the ways of controlling exposures to welding fumes and gases, and is intended primarily as a source of information for welders, engineers, and health and safety professional. Discussion of how exposure to high levels of welding fumes and gases causes specific short-term and long term health effects. Recommendation for reduction and control of exposures to welding fumes and gases, substitution of less hazardous materials, use of engineering controls and good work practices.

Final Report

Appendix 2

Task 2 – Regulatory Impact Analysis

NATIONAL SHIPBUILDING RESEARCH PROGRAM

SNAME SHIP PRODUCTION COMMITTEE
SP-7 Welding
7-96-9

WELDING FUME STUDY
Task 2 - Regulatory Impact Analysis
Interim Deliverable

August 1, 1997

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TABLE OF CONTENTS

ATTACHMENTS

1.0 Introduction

The purpose of the Task 2 - Regulatory Impact Analysis of the Welding Fume Study was to evaluate the status of proposed changes to Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) and the American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values (TLVs) for exposures to chromium (Cr), hexavalent chromium (CrVI), nickel (Ni) and manganese (Mn) and to determine what impact these regulatory changes may be expected to have on the shipyard welding industry. The Navy and the National Shipbuilding Research Program SP-7 Welding Panel are concerned about the potential effect on cost of operations of anticipated reductions in OSHA and ACGIH worker exposure limits for welding fume airborne emissions.

Welding fumes contain a variety of occupationally hazardous elements which include Cr, Cr(VI), Ni and Mn. These fume elements are encountered by workers engaged in welding and thermal cutting operations, especially those involving stainless steel and high strength steel alloys. Current OSHA regulations limit worker exposure to Cr(VI) to a concentration of 100 ug/m^3 based on an eight hour time weighted average. OSHA is considering safety and health standard amendments to reduce the Cr(VI) PEL to somewhere in the range of 0.5 ug/m^3 to 10 ug/m^3. The ACGIH recently reduced the TLV for Mn fume from 1,000 ug/m3 to 200 ug/m3 and has announced plans to reduce the TLV for Ni from 1,000 ug/m3 to 100 ug/m3 for insoluble Ni compounds and to 50 ug/m3 for soluble Ni compounds.

To ensure compliance with these limits employers currently use personal protection equipment (respirators) and engineering controls (ventilation systems) for approximately 12% of shipyard related welding activities. Compliance with these more stringent exposure standards will require significant allocations of

resources to worker training, respirator equipment, ventilation system equipment, exposure monitoring, medical surveillance and industrial hygiene planning. The subject elements are most often encountered in shipbuilding and in ship repair/maintenance activities, especially those involving welding and thermal cutting operations. The proposed rule changes will have important effects on operations and costs in the marine services industry. At a PEL of 5.0 ug/m^3 for Cr(VI), employers will need to provide respirator protection to welding trade workers for about 50% ship building/repair/maintenance activities. At a PEL of 0.5 ug/m^3 for Cr(VI) marine industry employers will need to provide respirator protection to welding trade workers for almost 100% of activities. Protection of other workers in the nearby work space environment will require provision of isolation and ventilation system equipment for many welding/thermal cutting operations if the proposed exposure limit changes are implemented. Since the predominant U. S. client for ship building, maintenance, and repair services is the Navy, the proposed exposure limit changes will have major effects on the cost and efficiency of operations necessary for national security.

This report describes a cost estimation model constructed to aid in assessing the potential economic impact of the proposed regulatory changes. A detailed description of the structure of the model in terms of the variables involved and the computational algorithms used to derive cost impacts is presented followed by the analysis of the variable values used in an initial implementation of the model to produce preliminary cost estimates. Also identified are areas where additional research and data collection is needed to improve the accuracy of the model's results. The preliminary cost estimates derived using the model and findings regarding the sensitivity of anticipated costs to key variables and regulatory provisions are presented in Attachment A.

2.0 Overview Of Anticipated Rule Requirements

The central feature of the proposed regulation is the requirement that employers ensure that workers are not exposed to the subject elements at levels above the new, more stringent PELs. Exposure to these elements, particularly Cr(VI), are already regulated, but the threshold exposure level is such that direct action to provide protective equipment or engineering controls is seldom necessary. The costs associated with the current rules are primarily felt through the need to provide training to workers to enable them to recognize hazardous situations and to know how to properly use respiratory protection in the small number of circumstances where it is now necessary. The proposed changes will reduce the exposure limits to a point where a much higher rate of protection response action will be needed. It is expected that the proposed standards will be performance based allowing the employer to determine the methods necessary to meet compliance requirements. Engineering controls may include local exhaust ventilation. Respiratory personal protective equipment may be necessary in many instances.

A key element in the proposed rule changes is that employers must demonstrate and document a negative exposure assessment for all work tasks where protective action is not taken. This provision will greatly increase the necessity to undertake air monitoring and to evaluate individual work tasks and circumstances. In ship building, maintenance and repair establishments, where work sites, materials and processes are continually changing, the negative exposure assessment criterion may have the practical effect of causing some actually safe work situations to be treated as exposure hazards because of the lack of time or resources to produce a negative exposure assessment.

3.0 Categories of Compliance Costs

The proposed regulation changes will impose four broad categories of operational and overhead costs on employers: Personal protection equipment, lost productivity, engineering controls, and general compliance safety program costs. Each of these categories are comprised of several elements which are described below. In most cases each of these cost categories is already applicable under the current regulation, but compliance with the proposed new regulations will increase the incidence of these costs.

Personal protection equipment costs include the cost of supplying respirators to employees, including the cost of consumable supplies such as High Efficiency Particulate Air (HEPA) filters and respirator maintenance. The types of respirators most often required are expected to be half or full mask air-purifying devices equipped with HEPA filters. In cases of high exposure (as already required under current rules) supplied air systems will be required. Personal protection equipment cost also includes the expense of providing and maintaining protective clothing for workers to use during hazardous tasks to reduce the risk of exposure to residues remaining on clothes after leaving the work site. It is assumed that under terms of the current regulation respirators and protective clothing are available to all workers from common stocks, but are used much less frequently than would be the case under the proposed rule revisions. The proposed regulation changes will result in more instances of use of personal protection equipment, resulting in need for greater stocks of equipment relative to workforce size, greater consumption of HEPA filters and respirators, higher maintenance/repair costs, and shorter equipment service life.

Lost worker productivity is composed of several elements: Setup time for engineering controls (ventilation systems) and personal protection equipment (drawing respirators from supply stocks and checking fit), cleanup, clothes

changing and showering time, worker time spent for medical surveillance examinations and fit testing, worker time for training, and additional worker time on-task required because of the cumbersomeness of protective equipment and control system work restrictions. This category has the greatest potential for proposed regulation changes to impose costs. It is also the category for which the least empirical data for cost estimation is available. The current report presents estimates for this cost category based on subjective estimates of key parameter values, but it is strongly recommended that research resources be devoted to careful empirical data collection regarding the lost productivity parameters before final regulation revision decisions are made.

Engineering controls costs refer to the cost of mobile and fixed ventilation systems to remove fumes from the work area and/or dilute fumes with fresh outside air. These costs include the ventilator units, work area enclosure systems for use with the ventilators, ducting to connect systems with outside air sources, and maintenance and consumable materials (filters, etc.) associated with ventilation system use. Given the apparent nature of shipbuilding, maintenance and repair work, it is expected that mobile ventilation systems will be the primary means of engineering controls for welding operations. At present such systems are seldom used for routine production welding. It is expected that the proposed revisions of Cr(VI) standard will require much more extensive use of such systems: perhaps including all welding activities conducted within enclosed ship spaces. It is anticipated that more than one welder may be serviced by such a system simultaneously, but this assumption requires further investigation to validate and clarify it.

General safety and compliance costs include the instructional and materials expenses of training, the direct expenses associated with air monitoring, medical surveillance, provision of hygiene facilities, and the expenses of conducting research and investigations to establish and maintain written compliance plans,

and to accomplish compliance record keeping. It is anticipated that costs for additional air monitoring (because of the negative exposure assessment requirement) and medical surveillance (because of increased incidence of respirator use) will be the most significant elements of cost increase under the proposed rule changes. Training cost is not expected to increase significantly, because most employers in ship building, repair and maintenance establishments are already obligated to provide training under existing standards. The present extensiveness of training (verified by responses of employers to the DynCorp compliance survey) derives from the fact that most welding workers now must use respirators sometimes, albeit infrequently. The current pattern of usage already triggers near universal training. Air monitoring is currently done infrequently, because the current rule does not include a negative exposure assessment provision. The anticipated negative exposure provision in the new Cr(VI) rule may trigger much higher air monitoring rates. Medical surveillance costs may also increase because higher incidence of situations requiring respiratory protection may result in more workers falling under that provision of the Cr(VI) rule. Record keeping and related administrative costs may increase because of the anticipated requirement to create and maintain a comprehensive compliance plan. Firms may also find it necessary to invest in new or expanded showers, change areas and other hygiene facilities because of the higher incidence of use of protective clothing.

4.0 Methods of Calculating Compliance Costs

A computer spreadsheet analysis model was developed to support the calculation of compliance costs described in this report. The model uses thirty nine user supplied parameters to calculate estimated per worker compliance costs and industry total costs. The structure of the model is oriented toward costs specifically arising through the welding activities context. For purposes of this report parameter values were selected to reflect the specific context of welding in the ship building, repair and maintenance industry. Industry total costs were calculated based on estimated numbers of welders in shipbuilding, maintenance and repair. It is recognized that the economy-wide impact of the proposed regulations will include compliance costs associated with workers in other industry segments besides ship building, maintenance and repair and in other trades besides welding. Therefore, the costs estimated by the model for this report represent only a fraction (but an important one) of the economy-wide costs of the proposed regulatory changes. **It was also assumed that the costs of complying with the proposed Cr(VI) rule and the proposed changes in Mn and Ni exposure limits are completely joint and are driven by the Cr(VI) limits. This assumption implies that there are no separate additional costs associated with Mn and Ni limit compliance not already subsumed under Cr(VI) compliance costs.** The computer model provides for user entry of four different scenario values for each parameter: a value for each parameter applicable to the current Cr(VI) rule and a value for each parameter applicable to each of three alternative levels for Cr(VI) limits currently under consideration; 10.0 , 5.0 and 0.5 ug/m^3 .

Table 1 lists the parameter abbreviation names and descriptions for each of the thirty-nine parameters used in the model.

Table 1 **Definitions of Welding Fume Rule Compliance Cost Model Parameters**	
Variable Designator	**Description**
V1	Number of half-mask air purifying respirators supplied for each worker
V2	Number of supplied air respirators supplied for each worker
V3	Average service life (in years) of half mask respirator
V4	Average service life (in years) of supplied air respirator
V5	Acquisition cost per air purifying respirator
V6	Acquisition cost per supplied air respirator
V7	Annual cost of maintenance and supplies for half mask air purifying respirator
V8	Annual cost of maintenance and supplies for supplied air respirator
V9	Number of protective clothing sets provided for each worker
V10	Average service life of protective clothing set
V11	Acquisition cost of a protective clothing set
V12	Annual maintenance cost per protective clothing set
V13	Average hours per day typical worker uses to set up/take down portable ventilation systems
V14	Average hours per day to obtain and adjust respirators
V15	Average hourly labor cost
V16	Hours length of typical training session
V17	Average daily hours per worker cleaning, changing & showering
V18	Worker time per medical exam and testing instance
V19	Worker productivity at task as percent of productivity absent any fume safety precautions
V20	Number of ventilation units provided per worker
V21	Average cost per ventilation unit
V22	Average service life of ventilation unit
V23	Annual cost of maintenance and supplies per ventilation unit
V24	Number of exposed workers at typical site

Table 1 Definitions of Welding Fume Rule Compliance Cost Model Parameters	
Variable Designator	**Description**
V25	Cost of instruction and materials per training session
V26	Typical training class size
V27	Cost for data collection and testing per air monitoring instance
V28	Annual number of air monitoring instances at typical site
V29	Cost of examination and testing per worker medical surveillance exam
V30	Annual frequency of medical surveillance exams
V31	Percent of exposed workers subject to medical surveillance
V32	Cost of construction of shower/cleanup facility
V33	Worker capacity of typical shower/cleanup facility
V34	Annual total cost of compliance administration (record keeping, compliance planning, supervision, and inspection) at typical site
V35	Industry-wide number of workers affected
V36	Number of working days per year for typical exposed worker
V37	Number of exposure days per year for typical exposed worker
V38	Average hours worked per day
V39	Annual training sessions per worker

The parameter values entered by the model user are used in mathematical functions to calculate the values for nine per-worker cost variables defined in Table 2.

Table 2
Welding Fume Cost Estimation Model
Cost Element Variable Functions

Variable	Description	Functional Specification
V40	Per worker cost of respiratory protection	((V5/V3)+V7)*V1+((V6/V4)+V8)*V2
V41	Per worker cost of protective clothing	((V11/V10)+V12)*V9
V42	Per worker cost of lost productive time and efficiency	(V13*V37 +V14*V37+ V16*V39+ V17*V37+ V18*V30*V31+ ((V38/V19) -V38)*V37)*V15
V43	Per worker cost of engineering controls	+V20*((V21/V22)+V23)
V44	Per worker cost of training materials and instruction	+V25/V26
V45	Per worker cost of air monitoring	+V27*V28/V24
V46	Per worker cost of medical surveillance	+V29*V30*V31
V47	Per worker cost of hygiene facilities	+V32/V33
V48	Per worker cost of administration	+V34/V24

The nine cost element variables (V40 through V48) are then summed to calculate per worker total compliance cost. Per worker cost is multiplied by the applicable number of affected workers (parameter V35) to obtain an estimate of industry-wide total cost. For each of the three alternative rule exposure limit scenarios, the total industry cost for that scenario is subtracted from the current rule total cost to obtain net compliance cost for that version of the proposed rule change.

5.0 Parameter Values

Table 3 displays the values used for each parameter to calculate the preliminary cost estimates reported herein.

Table 3 Welding Fume Regulation Economic Impact Model					
Variable Description	**Variable Name**	**Current PEL Value**	**Alternative 1 Value**	**Alternative 2 Value**	**Alternative 3 Value**
		100 ug/m3	**10 ug/m3**	**5 ug/m3**	**0.5 ug/m3**
Number of half-mask air purifying respirators supplied for each worker	V1	0	0.0225	0.14	0.88
Number of supplied air respirators supplied for each worker	V2	0.12	0.12	0.12	0.12
Average service life (in years) of half mask respirator	V3	2	2	2	2
Average service life (in years) of supplied air respirator	V4	2	2	2	2
Acquisition cost per air purifying respirator	V5	20	20	20	20
Acquisition cost per supplied air respirator	V6	300	300	300	300
Annual cost of maintenance and supplies for half mask air purifying respirator	V7	500	500	500	1500
Annual cost of maintenance and supplies for supplied air respirator	V8	500	500	500	500
Number of protective clothing sets provided for each worker	V9	0	1	1	1
Average service life of protective clothing set	V10	0.5	0.4	0.3	0.25
Acquisition cost of a protective clothing	V11	50	50	50	50

Table 3 Welding Fume Regulation Economic Impact Model					
Variable Description	**Variable Name**	**Current PEL Value**	**Alternative 1 Value**	**Alternative 2 Value**	**Alternative 3 Value**
		100 ug/m3	**10 ug/m3**	**5 ug/m3**	**0.5 ug/m3**
set					
Annual maintenance cost per protective clothing set	V12	150	150	150	150
Average hours per day typical worker uses to set up/take down portable ventilation systems	V13	0.25	0.25	0.5	0.5
Average hours per day to obtain and adjust respirators	V14	0.25	0.25	0.25	0.25
Average hourly labor cost	V15	50	50	50	50
Hours length of typical training session	V16	2	2	2	2
Average daily hours per worker cleaning, changing & showering	V17	0.5	0.5	0.5	0.5
Worker time per medical exam and testing instance	V18	2	2	2	2
Worker productivity at task as percent of productivity absent any fume safety precautions	V19	0.95	0.95	0.95	0.95
Number of ventilation units provided per worker	V20	0.01	0.05	0.1	0.2
Average cost per ventilation unit	V21	4000	4000	4000	4000
Average service life of ventilation unit	V22	5	5	5	5
Annual cost of maintenance and supplies per ventilation unit	V23	500	500	500	500
Number of exposed workers at typical site	V24	1000	1000	1000	1000
Cost of instruction and materials per training session	V25	1000	1000	1000	1000

Table 3
Welding Fume Regulation Economic Impact Model

Variable Description	Variable Name	Current PEL Value	Alternative 1 Value	Alternative 2 Value	Alternative 3 Value
		100 ug/m3	10 ug/m3	5 ug/m3	0.5 ug/m3
Typical training class size	V26	20	20	20	20
Cost for data collection and testing per air monitoring instance	V27	200	200	200	200
Annual number of air monitoring instances at typical site	V28	232	1195	1195	1195
Cost of examination and testing per worker medical surveillance exam	V29	250	250	250	250
Annual frequency of medical surveillance exams	V30	1	1	1	1
Percent of exposed workers subject to medical surveillance	V31	0.1	0.25	0.5	1
Cost of construction of shower/cleanup facility	V32	20000	20000	20000	20000
Worker capacity of typical shower/cleanup facility	V33	50	50	50	50
Annual total cost of compliance administration (record keeping, compliance planning, supervision, and inspection) at typical site	V34	10000	50000	50000	50000
Industry-wide number of workers affected	V35	28000	28000	28000	28000
Number of working days per year for typical exposed worker	V36	250	250	250	250
Number of exposure days per year for typical exposed worker	V37	25	100	200	250
Average hours worked per day	V38	8	8	8	8
Annual training sessions per worker	V39	1	1	1	1

6.0 Basis for Parameter Estimates

Parameter values shown in Table 3 represent preliminary estimates based on review of available literature, discussions with industry representatives, and subjective evaluations of analysts. Review of "Impact of Recent and Anticipated Changes in Airborne Emission Exposure Limits on Shipyard Workers", NSRP 0463 (March 1996) (cited infra as NSRP 0463) was a source for many of the preliminary parameter estimates. This report described and analyzed findings from a survey of 26 Navy facilities and 6 private shipyards conducted by Naval Surface Warfare Center. The facilities surveyed represented employment establishments covering approximately 5,000 of the 28,000 industry-wide welders. Additional information was provided by seven industry informants who responded to questions posed by DynCorp. Additional parameter values were estimated by this analyst based on prior experience and discussions with DynCorp safety professionals. It is recommended that each of these values be reviewed, further investigated and validated based on empirical data to be collected during field inspections. Table 4 displays information regarding the basis for each of the parameter values on which preliminary cost estimates are based.

Table 4 Welding Fume Compliance Cost Model Basis for Preliminary Parameter Values		
Variable Description	**Variable Name**	**Basis**
Number of half-mask air purifying respirators supplied for each worker	V1	Imputed from ratios of expected exposure incidence reported in NSRP 0463 (March 1996). This report showed average exposure incidence for a 10 ug/m^3 PEL to be 16% of the incidence for a 5.0 ug/m^3 PEL and that to be 16% of incidence for a 0.5 ug/m^3 PEL. Assumed half-mask respirators would be used in all activities under 0.5 ug/m^3 PEL not already covered by use of air supplied respirators under current PEL.
Number of supplied air respirators supplied for each worker	V2	Estimate based on activity exposure data for current PEL reported in NSRP 0463 (March 1996)
Average service life (in years) of half mask respirator	V3	Information supplied by industry informants
Average service life (in years) of supplied air respirator	V4	Information supplied by industry informants
Acquisition cost per air purifying respirator	V5	Information supplied by industry informants
Acquisition cost per supplied air respirator	V6	Information supplied by industry informants
Annual cost of maintenance and supplies for half mask air purifying respirator	V7	Information supplied by industry informants
Annual cost of maintenance and supplies for supplied air respirator	V8	Information supplied by industry informants
Number of protective clothing sets provided for each worker	V9	Analyst estimate

Table 4 Welding Fume Compliance Cost Model Basis for Preliminary Parameter Values		
Variable Description	**Variable Name**	**Basis**
Average service life of protective clothing set	V10	Analyst estimate
Acquisition cost of a protective clothing set	V11	Analyst estimate
Annual maintenance cost per protective clothing set	V12	Analyst estimate
Average hours per day typical worker uses to set up/take down portable ventilation systems	V13	Analyst estimate
Average hours per day to obtain and adjust respirators	V14	Analyst estimate
Average hourly labor cost	V15	NSRP 0463 (March 1996)
Hours length of typical training session	V16	NSRP 0043 (March 1996
Average daily hours per worker cleaning, changing & showering	V17	Analyst estimate
Worker time per medical exam and testing instance	V18	NSRP 0043 (March 1996)
Worker productivity at task as percent of productivity absent any fume safety precautions	V19	Analyst estimate. This is a critical variable. Results are extremely sensitive to this value
Number of ventilation units provided per worker	V20	Analyst estimate
Average cost per ventilation unit	V21	Information provided by industry informants

Table 4 **Welding Fume Compliance Cost Model** **Basis for Preliminary Parameter Values**		
Variable Description	**Variable Name**	**Basis**
Average service life of ventilation unit	V22	Information provided by industry informants
Annual cost of maintenance and supplies per ventilation unit	V23	Information provided by industry informants
Number of exposed workers at typical site	V24	1000 workers site employment selected to match source used in NSRP estimates of fixed costs components
Cost of instruction and materials per training session	V25	NSRP 0463
Typical training class size	V26	NSRP 0463
Cost for data collection and testing per air monitoring instance	V27	NSRP 0463
Annual number of air monitoring instances at typical site	V28	Derived from NSRP report estimates of sampling increase (585%) relative to analyst estimate of current sampling.
Cost of examination and testing per worker medical surveillance exam	V29	NSRP 0463
Annual frequency of medical surveillance exams	V30	Anticipated rule requirement
Percent of exposed workers subject to medical surveillance	V31	Analyst estimate
Cost of construction of shower/cleanup facility	V32	Analyst estimate
Worker capacity of typical	V33	Analyst estimate

Table 4 **Welding Fume Compliance Cost Model** **Basis for Preliminary Parameter Values**		
Variable Description	**Variable Name**	**Basis**
shower/cleanup facility		
Annual total cost of compliance administration (record keeping, compliance planning, supervision, and inspection) at typical site	V34	NSRP 0463
Industry-wide number of workers affected	V35	Bureau of Labor Statistics
Number of working days per year for typical exposed worker	V36	Analyst estimate
Number of exposure days per year for typical exposed worker	V37	Analyst estimate
Average hours worked per day	V38	Analyst estimate
Annual training sessions per worker	V39	Anticipated rule requirement

7.0 Compliance Cost Findings

Implementation of the compliance cost estimation model described above showed significant cost increases associated with each of the alternative Cr(VI) PEL alternatives. As expected the greatest cost increase, compared to the current rule cost, was found for the 0.5 ug/m^3 alternative: **$604,386,779**. This amount equivalent to $24,094 per affected worker represents a 25% annual increase in the employer cost per worker (based on a $50 per hour current cost fully loaded with overhead burden). Compared to the estimated cost of the current regulation, it is an eight-fold increase. Table 5 shows the model calculation results for each alternative in terms of total per worker cost, annual total industry-wide cost and net total industry wide cost. The table also shows the breakdown (in terms of cost per worker) for the current rule and each alternative PEL by major cost components.

Table 5
Welding Fume Rule Compliance Cost Model Results

	Current PEL	10 ug/m^3 PEL	5.0 ug/m^3 PEL	0.5 ug/m^3 PEL
Cost of respiratory protection	$78	$89	$149	$1,407
Cost of protective clothing	$0	$275	$317	$350
Lost productivity cost	$1,886	$7,230	$16,861	$21,088
Cost of ventilation systems	$13	$65	$130	$260
Training direct cost	$50	$50	$50	$50
Air monitoring cost	$46	$239	$239	$239
Medical surveillance cost	$25	$62	$125	$250
Hygiene facility cost	$400	$400	$400	$400
Administrative cost	$10	$50	$50	$50
Total per worker cost	$2,509	$8,461	$18,321	$24,094
Annual industry-wide cost	$70,244,042	$236,914,668	$512,976,604	$674,630,821
Net cost of rule change		$166,670,626	$442,732,561	$604,386,779

The largest single cost item is lost productivity cost. The value of this item is highly sensitive to the parameter "Number of exposure days per year for the typical worker." This parameter was set at values of 25, 100, 200, and 250 for the current and three successively more stringent alternative scenarios. For comparison, setting these parameters at the values 25, 50, 100, and 150 results in a reduction of annual costs for each alternative by over $200 million per year. No empirical data was available for estimating the value of this critical parameter. Clearly the issue of average exposure days per work should be given foremost attention during field inspection and research phases of the assessment project.

A Lotus 123 (version 5) spreadsheet file, FUMEMODL.WK4 has been delivered in tandem with this report. The results section of the spreadsheet (similar to Table 5 of this report) automatically recalculates the compliance cost estimates when new values are substituted for any parameter. DynCorp has provided the spreadsheet model to allow users to explore the effect of parameter changes on compliance cost as a guide to formulating field inspection data collection strategies.

Task 2

Attachment A

Welding Fume Regulation Economic Impact Model

Welding Fume Regulation Economic Impact Model

Variable Description	Current PEL Value 100 mg/c3	Alternative 1 Value 10mg/c3	Alternative 2 Value 5mg/c3	Alternative 3 Value 0.5mg/c3
Number of half-mask air purifying respirators supplied for each worker	0	0.0225	0.14	0.88
Number of supplied air respirators supplied for each worker	0.12	0.12	0.12	0.12
Average service life (in years) of half mask respirator	2	2	2	2
Average service life (in years) of supplied air respirator	2	2	2	2
Acquisition cost per air purifying respirator	20	20	20	20
Acquisition cost per supplied air respirator	300	300	300	300
Annual cost of maintenance and supplies for half mask air purifying respirator	500	500	500	1500
Annual cost of maintenance and supplies for supplied air respirator	500	500	500	500
Number of protective clothing sets provided for each worker	0	1	1	1
Average service life of protective clothing set	0.5	0.4	0.3	0.25
Acquisition cost of a protective clothing set	50	50	50	50
Annual maintenance cost per protective clothing set	150	150	150	150
Average hours per day typical worker uses to set up/take down portable ventilation systems	0.25	0.25	0.5	0.5
Average hours per day to obtain and adjust respirators	0.25	0.25	0.25	0.25
Average hourly labor cost	50	50	50	50
Hours length of typical training session	2	2	2	2
Average daily hours per worker cleaning, changing & showering	0.5	0.5	0.5	0.5
Worker time per medical exam and testing instance	2	2	2	2
Worker productivity at task when using protective gear and systems as percent of productivity absent any fume safety precautions	0.95	0.95	0.95	0.95
Number of ventilation units provided per worker	0.01	0.05	0.1	0.2
Average cost per ventilation unit	4000	4000	4000	4000
Average service life of ventilation unit	5	5	5	5
Annual cost of maintenance and supplies per ventilation unit	500	500	500	500
Number of exposed workers at typical site	1000	1000	1000	1000
Cost of instruction and materials per training session	1000	1000	1000	1000
Typical training class size	20	20	20	20
Cost for data collection and testing per air monitoring instance	200	200	200	200
Annual number of air monitoring instances at typical site	232	1195	1195	1195

Cost of examination and testing per worker medical surveillance exam	250	250	250	250	
Annual frequency of medical surveillance exams	1	1	1	1	
Percent of exposed workers subject to medical surveillance	0.1	0.25	0.5	1	
Cost of construction of shower/cleanup facility	20000	20000	20000	20000	
Worker capacity of typical shower/cleanup facility	50	50	50	50	
Annual total cost of compliance administratio (recordkeeping, compliance planning, supervision, and inspection) at typical site	10000	50000	50000	50000	
Industry-wide number of workers affected	28000	28000	28000	28000	
Number of working days per year for typical exposed worker	250	250	250	250	
Number of exposure days per year for typical exposed worker	25	100	200	250	
Average hours worked per day	8	8	8	8	
Annual training sessions per worker	1	1	1	1	
Results					
Cost of respiratory protection	$78	$89	$149	$1,407	per worker
Cost of protective clothing	$0	$275	$317	$350	per worker
Lost productivity cost	$1,886	$7,230	$16,861	$21,088	per worker
Cost of ventilation systems	$13	$65	$130	$260	per worker
Training direct cost	$50	$50	$50	$50	per worker
Air monitoring cost	$46	$239	$239	$239	per worker
Medical surveillance cost	$25	$63	$125	$250	per worker
Hygiene facility cost	$400	$400	$400	$400	per worker
Administrative cost	$10	$50	$50	$50	per worker
Total per worker cost	**$2,509**	**$8,461**	**$18,321**	**$24,094**	
Annual industry-wide cost	**$70,244,042**	**$236,914,668**	**$512,976,604**	**$674,630,821**	
Net cost of rule change		**$166,670,626**	**$442,732,561**	**$604,386,779**	

Final Report

Appendix 3, Task 3

Field Evaluation

March 6, 1998

Mr. John Meacham
Program Manager
Peterson Builders, Incorporated
Industrial Engineering Department
101 Pennsylvania Avenue
Sturgeon Bay, WI 54235

Subject: Task No. 3, NSRP Project 7-96-9, Welding Fume Study

Mr. Meacham:

Attached is the Task No. 3 Report, Field Evaluations, prepared by DynCorp in accordance with Project 7-96-9. A total of four hard copies have been provided in three ring binders. The body of the report is provided in Microsoft Word 6.0 electronic format on one 3.5” disc. The DynCorp Welding Fume Database is provided in Microsoft ACCESS electronic format on a second 3.5” disc.

DynCorp is currently working on the Draft Final Report. It is estimated that the Draft Final Report shall be completed and delivered to you by March 16, 1998.

If you have any questions or require additional information, please call me at (703) 264-8770.

Sincerely,

Daniel O. Chute, CIH, CSP
Director
Environmental Health & Safety Services

NATIONAL SHIPBUILDING
RESEARCH PROGRAM

SNAME PRODUCTION COMMITTEE
SP-7 Welding
7-96-9

WELDING FUME STUDY
TASK NO. 3 - FIELD EVALUATION
INTERIM DELIVERABLE

March 6, 1998

Submitted to:

Mr. John Meacham, Program Manager
Peterson Builders, Incorporated
Industrial Engineering Department
101 Pennsylvania Avenue
Sturgeon Bay, Wisconsin 54235

Submitted by:

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TABLE OF CONTENTS

ATTACHMENTS

EXECUTIVE SUMMARY

The purpose of the Welding Fume Study Task No. 3 - Field Evaluations was to observe and collect the latest available information on the status of engineering control measures for welding fume exposures to nickel, manganese, chromium, and hexavalent chromium. DynCorp identified six target engineering controls for evaluation and then visited six shipyards around the country to evaluate the fume control measures and collect data.

The six shipyards which participated in the Field Evaluations were NORSHIPCO, Lake Shore, Incorporated, National Steel & Shipbuilding Company (NASSCO), Alabama Shipyard, Incorporated, Ingalls Shipbuilding, and Bath Ironworks.

DynCorp identified the fume control measures for evaluation based upon research conducted during Task No. 1 - Literature Search and commercial availability. The six fume control methods targeted for evaluation were fume extractor guns, fixed fume extraction systems, portable fume extraction systems, low fume welding wires, downdraft/backdraft tables, and fume filtration devices.

Field evaluation data collection elements were identified using recognized industry guidelines and assembled into a customized electronic database using Microsoft ACCESS. Fume control measures in use at each shipyard were observed and evaluated. Air monitoring for Cr6, Cr, Ni and Mn was performed. Data collected was compiled on laptop computers carried in the field. When permitted, digital photographs were taken of the processes.

Current shipyard practices place little emphasis on controlling employee exposures to welding fumes. Existing engineering controls reduce, but do not eliminate worker exposures to fumes. A reduction of the OSHA PELs for welding fumes is likely to result in advances in engineering controls for welding fumes due to market demand.

Based upon Field Evaluations observations, shipyards may want to approach the problem of worker exposure to welding fumes by establishing performance criteria for fume exposures which would apply to the entire life cycle of the construction of a ship, beginning at the initial design phase of a project and following through to the completed product.

1.0 Introduction

The purpose of the Welding Fume Study Task No. 3 - Field Evaluations was to observe and collect the latest available information on the status of control measures for welding fume exposures to nickel (Ni), manganese (Mn), chromium (Cr), and hexavalent chromium (Cr6). The scope of work included shipyard site visits to evaluate existing fume control measures, collection of data, conclusions and recommendations.

DynCorp organized the shipyard site visits through contacts at the Center for Advanced Ship Repair and Maintenance and through SP-7 Panel members at shipyards. A total of six shipyards around the continental United States participated. The size of the shipyards ranged from less than 100 workers to more than 12,000 workers.

During the research phase of Task No. 1 - Information Search, six common fume control methods were selected for Field Evaluation. Each were readily available on the commercial market which included fume extractor guns, fixed fume extraction systems, portable fume extraction systems, low fume welding wires, downdraft/backdraft tables, and fume filtration devices. These six fume control measures were targeted for air monitoring and evaluation during the Task No. 3 - Field Evaluations.

Fully equipped Industrial Hygienist were dispatched to each participating shipyard to collect a wide variety of data related to fume control methods based upon OSHA prescribed air sampling techniques and guidelines published by the American Welding Society (AWS) and the American Industrial Hygiene Association (AIHA). The Industrial Hygienists compiled all information gathered into the Welding Fume Database (WFD) on portable laptop computers.

This project was conducted under the direction of Mr. Daniel O. Chute, Certified Industrial Hygienist and Certified Safety Professional. Coordination of site visits, collection of field data, laboratory analysis, and reporting was under the direction of the Project Manager, Mr. Bradley W. Christ, Associate Safety Professional.

2.0 Shipyard Site Visits

Once the target welding fume control methods for the Field Evaluation task were identified, the project team worked with SP-7 Panel members to initiate contact with shipyards around the country in an effort to determine locations where the processes were in operation and could be observed. Manufacturers of related process equipment were also contacted to determine which shipyards were using the equipment.

Site visits were conducted in Virginia, Wisconsin, Michigan, Alabama, Mississippi, and California. Engineering controls observed included all the targeted engineering control methods, with the exception of downdraft/backdraft tables and portable fume filtration systems, neither of which could be located in any of the shipyards contacted. Several shipyards provided historical air monitoring data for Ni, Mn, Cr, and Cr6. On-site work included collection of detailed evaluation data, photographs of the control methods (where permitted), and ventilation measurements.

NORSHIPCO

The NORSHIPCO shipyard site visit was conducted on September 22-23, 1997. NORSHIPCO is located in Norfolk, Virginia. The welding fume control methods in use during the site visit consisted of low fume welding wires and portable fume extraction systems. The shipyard contact was Mr. Tom Beacham.

The workers selected for air monitoring were three welders performing bulkhead welding inside the Mt. Baker ship, two workers performing bulkhead fabrication and small tasks in Welding Shop Building #620, and one worker performing general fabrication in Plate Shop Building #619.

Lake Shore, Incorporated

The Lake Shore, Incorporated shipyard site visit was conducted on October 22-23, 1997. Work was conducted at the Lake Shore production facility in Rhinelander, Wisconsin and then continued at the shipyard facility in Ontonagon, Michigan for air monitoring. The shipyard contact was Mr. Bruce Halverson, Manager - Fabrication Services.

The workers selected for air monitoring included one welder performing production fabrication on a movable hydraulic jig using a fume extractor gun, one welder welding inside a barge hull using a portable fume extraction system, and one welder performing general fabrication using a fume extractor gun.

During the Field Evaluations, Lake Shore was the only facility using fume extraction guns. Workers reported that the guns greatly reduced the overall production of fumes within the facility. Workers noted that the guns were slightly bulkier and somewhat more difficult to use in very tight spaces, but overall workers reported that they preferred to use the fume extraction torches. Fumes collected by the fume extractor guns were processed through a permanently mounted fume filtration device.

Lake Shore was highly involved in the evaluation of effective control measures for fume control for worker protection. Mr. Halverson had dedicated considerable time and effort to design an integrated exhaust system within the production facility that was dedicated to the fume extraction gun system. He was also involved in the administration of the respiratory protection program in place at Lake Shore, which included ongoing review and employee feedback. Several employees at the Rhinelander facility were observed using powered air purifying respirators built into their welding helmets. The employees all commented favorably regarding the powered air purifying respirators, although each worker admitted that it took a little time to get used to wearing one and that it required an extra level of effort to plug the batteries into a charger at the end of each shift.

National Steel & Shipbuilding Company (NASSCO)

The NASSCO shipyard site visit was on January 27-28, 1998. NASSCO is located in San Diego, California. The welding fume control methods in use during the site visit consisted of portable fume extraction systems, fixed fume extraction systems, and low fume welding wires. The shipyard contact was Mr. Mike Sullivan, Chief Welding Engineer.

The workers selected for air monitoring included four welders working outdoors performing general assembly, three welders performing bulkhead welding within inner hull bottom assemblies, one welder in the Pipe Shop Sub-assembly, and one welder in the Plate Shop.

Mr. Sullivan provided a great deal of assistance during the DynCorp site visit. He also played a key role in coordinating site visits with other shipyard facilities.

A majority of the welding performed at NASSCO was done outdoors due to the (normally) fair climate conditions found in southern California. Ventilation equipment and respiratory protection equipment was available to welders to use at their own discretion.

Alabama Shipyard, Incorporated

The Alabama Shipyard site visit was conducted on February 10-11, 1998. The welding fume control methods in use during the site visit consisted of low fume welding wires and portable ventilation systems. The shipyard contacts were Mr. Gregory Koprowitz, Welding Engineer, and Mr. Anand Ramamurthy, Industrial Engineer.

The workers selected for air monitoring included three welders working indoors in the Profile Shop, one welder working inside the Plate Shop, one welder working inside a deckhouse fixture, and six welders working inside a ship.

The shop facilities were observed to have excellent portable and fixed ventilation equipment. Shipboard ventilation systems consisted of random placement of supply ventilation from topside mounted fan units and scattered portable fume extraction blowers. All workers were provided with respiratory protection.

Ingalls Shipbuilding

The Ingalls Shipbuilding site visit was conducted on February 12, 1998. The welding fume control methods in use during the site visit consisted of low fume welding wires, fixed fume extraction systems, and portable fume extraction systems. The shipyard contact was Mr. Lee Kvidahl, Chief Welding Engineer.

The workers designated for air monitoring included one welder in the Panel Shop, two welders in the Electrical Shop, and three welders in the Sheet Metal Shop.

Bath Iron Works

The Bath Iron Works site visit was conducted on February 18-19, 1998. The welding fume control methods in use during the site visit consisted of portable fume extraction systems and low fume welding wires. The shipyard contact was Mr. David Forrest, Welding Engineer.

The workers designated for air monitoring included two welders in the B-Bay Fabrication Shop, two welders in the Fabrication Area, and two welders in the Tank Shop.

Shipyard	Number of Welders Observed	Engineering Control Observed
NORSHIPCO	6	Low Fume Welding Wires Portable Fume Extraction System
Lake Shore Incorporated	3	Fume Extractor Gun Portable Fume Extraction System
NASSCO	9	Portable Fume Extraction System Fixed Fume Extraction System Low Fume Welding Wires
Alabama Shipyard, Inc	11	Low Fume Welding Wires Portable Ventilation System
Ingalls Shipyard	6	Low Fume Welding Wires Fixed Fume Extraction System Portable Fume Extraction System
Bath Iron Works	6	Portable Fume Extraction System Low Fume Welding Wires

3.0 Control Measures Evaluated

Fume control measures were identified for evaluation based upon research conducted in Task No. 1 and commercial availability. A total of six fume control methods were targeted for evaluation, as summarized below.

Fume Extractor Guns

Fume Extractor Guns (FEG) are welding torches designed for partial capture of welding fumes generated at the welding source. FEG are currently limited to the gas metal arc welding (GMAW) and flux core arc welding (FCAW) processes. FEG are larger and heavier than normal GMAW and FCAW guns and require a dedicated exhaust system to draw welding fumes away from the plume. FEG can produce unacceptable welds if the operator has the exhaust ventilation rate to high and causes the welding shield gas to be withdrawn from the weld pool area. Welding in positions other than horizontal reduces the capture efficiency of the FEG. The additional bulk added to the gun by the exhaust nozzle and hose limits the ability of the welder to perform certain fit-ups and long term use could potentially lead to ergonomic problems for the welder. The current generation of FEGs have capture capability characteristics which vary between manufacturers and require the welder to fine tune the exhaust flow rate for each fit-up.

FEG are not in widespread use in the shipbuilding industry. During the Field Evaluations, only one participating shipyard, Lake Shore, was observed using the FEG. Welders at Lake Shore reported that the guns required some getting used to and were limited in application, but they were not adverse to using the FEGs and commented favorably on the reduction in fumes. Welders estimated that the FEGs could capture 40% to 60% of the fume generated at the weld pool, based on fit-up, welding position and wire type.

It should be noted that there is an ongoing research effort involving FEG performance and development at the Naval Surface Warfare Center in Carderock, Maryland. The program is under the direction of Mr. Ren Brenna and Mr. Gene Franke.

Fixed Fume Extraction Systems

Fixed Fume Extraction Systems (FFES) are rigid, permanently mounted welding fume exhaust systems. These systems are typically found in production shop areas. Examples are fixed hoods mounted over fabrication benches or exhaust ducts mounted above fixed welding process equipment in assembly line areas. Typically, there is one dedicated exhaust fan located on the roof of the facility that services several work areas. Fumes captured at the source are usually exhausted directly into the atmosphere from the building rooftop.

A wide variety of FFES were observed during the Field Evaluations. The FFES ranged from 6” in diameter to 20 square foot hoods. Welders usually had access to an on/off switch for the system somewhere in the shop, but had no control of the ventilation flow rate. Often the FFES hood was mounted above the welders head, allowing the fumes to travel through the welder breathing zone prior to entering the exhaust system. It was observed on several occasions that large items to be welded would not fit directly under the hood. Also, welders were often observed performing welding near, but not directly under the hood.

The efficiency of the FFES is limited to the placement of the object to be welded in relation to the capture point. The FFES provides an excellent opportunity to capture a majority of the fumes generated. This benefits workers in adjacent work areas, but does not always prevent exposure of the welder to the fumes. The FFES requires the welder to carefully position the object to be welded in order to optimize fume capture.

Portable Fume Extraction Systems

Portable Fume Extraction Systems (PFES) are designed to provide a welder with exhaust ventilation in field conditions. PFES range from lightweight blower units which can be handled by one person to large units which must be moved by mechanical apparatus from site to site or vessel to vessel. A typical PFES uses an electric motor to drive a blower unit connected to a flexible exhaust hose that the welder can position close to the weld pool. The amount of fume captured varies depending upon the design configuration of the inlet and the capture velocity at the inlet. The welding fumes captured are generally exhausted directly to the outside atmosphere.

A wide variety of PFES were observed during the Field Evaluations. The PFES requires the welder make constant adjustments to the position of the flexible exhaust hose inlet in order to optimize the fume capture. PFES do not capture all of the welding fume generated. It was observed that shipyard welders often set up the PFES at the beginning of the shift and make few if any adjustments to the exhaust hose inlet during welding operations. This practice limits the effectiveness of the equipment in maintaining effective exhaust ventilation. No written ventilation protocols were observed. Supervisors and workers typically had not received any type of training regarding ventilation. In cases where there were an insufficient number of PFES available, it was observed that welders may receive ventilation units based on seniority or first come, first serve.

Proper use of PFES requires a dedicated effort on the part of the welder. In order to maximize the efficiency of PFES, workers should be trained to properly use the PFES and supervisors should ensure that workers adhere to established PFES protocols.

Low Fume Welding Wires

There are many manufacturers marketing Low Fume Welding Wires (LFWW), however, there is no clear definition of LFWW composition or performance from the American Welding Society or any other standards organization. LFWW are generally associated with the FCAW process. FCAW has traditionally produced high fume emissions due to the composition of the cored wires. Manufacturers claim fume reductions ranging from 20% to 77% for the new generation of LFWW.

Four of the shipyards visited during the Field Evaluations were observed to use LFWW. Several welders noted that the LFWW were an improvement over the old wires, although some welders did not notice a significant difference. Some of the highest fume levels recorded during air monitoring occurred with welders using LFWW during FCAW in conjunction with 100% carbon dioxide (CO_2) shielding gas.

The composition of LFWW can effect fume emissions. The type of shielding gas selected will also effect the generation of fumes. Shielding with 100% CO_2 is generally believed to increase the fume generation rate because CO_2 disrupts the arc, reduces the arc stability, and reacts with the molten droplets to oxidize more metallic into the fume. The lack of an industry standard for the classification of LFWW limits its utility because it offers no standardized selection criteria for LFWW.

Downdraft/Backdraft Tables

Downdraft/Backdraft tables are fixed welding platforms constructed with a built in ventilation system which draws welding fumes either through table top or table wall perforations. Downdraft/Backdraft Tables requires a dedicated exhaust system which typically vents to the outside atmosphere. The sizes of Downdraft/Backdraft Tables range to accommodate from one welder to multiple welders. Advantages of the Downdraft/Backdraft Tables include no setup requirement for the welder, the welding fumes are exhausted away from the workers breathing

zone, and minimal maintenance. Disadvantages include initial setup cost and obstruction of the exhaust ventilation by the object being welded.

No participating shipyards were using Downdraft/Backdraft Tables during the Field Evaluations, however, several shipyards were observed to have production processes that could be modified to accommodate Downdraft/Backdraft technology. Large platen assembly areas would lend well to this type of fume extraction technology for certain production environments (small parts), but many fabrication practices in shipbuilding would not accomodate this type of fume extraction technology because the plates are first assembled to form the panel and then the parts are fitted and welded above the panel.

Fume Filtration Devices

Fume Filtration Devices (FFD) are ventilation systems which collect welding fumes and capture some of the airborne particulates at a filter. The level of filtration achieved is dependent upon the filtering device. Several portable and fixed FFD systems are commercially available and marketed for the welding industry. The portable systems range from briefcase size to refrigerator size.

An advantage of the FFD are that the fumes can be captured and, depending upon the level of filtration, the filtered air can be reintroduced into the heating, ventilation, and air conditioning (HVAC) system, greatly reducing utility costs. Aboard ships, the FFD eliminates the burden of running exhaust hose out of the vessel. Disadvantages include the initial purchase cost, filter replacement cost, and maintenance cost. Depending upon the welding process, the captured particulate may be classified as hazardous waste which increases disposal costs.

None of the participating shipyards were using portable FFD during the Field Evaluations. Lake Shore had a TORIT Filter Cartridge System Dust Collector, Model #TD163 dedicated to filtration of welding fumes captured by the FEG system. All air filtered by the TORIT unit was exhausted directly outside the building. Lake Shore management reported that the unit required little maintenance and that they were please with its performance.

4.0 Data Collected

Field Evaluation data collection elements for welding fumes were determined using guidelines established by the American Welding Society and the American Industrial Hygiene Association. A total of 52 data elements were identified for an Air Sample Data Entry Form.

To efficiently manage the sample data, a customized electronic data entry version of the Air Sample Data Entry Form using Microsoft ACCESS. The decision to use ACCESS software allowed grouping of all information gathered into the centralized WFD and provided a wide variety of options for working with the data, including custom queries and graphing. The electronic Air Sample Data Entry Form was developed to include drop down windows for many of the elements in order to provide both speed and consistency in the data entry process. An example of the Air Sample Data Entry Form is presented in **Attachment A**.

Once the means of data tabulation was established, the research team began the Field Evaluations. Each participating shipyard provided access to welders performing normal shipyard operations who were using one or a combination of the target fume control methods. Each designated welder wore two air sample collection pumps with for the duration of their work shift. Each of the air cassettes were affixed to the top of the workers collar in a position where it was covered by the welding helmet when the helmet was lowered. One cassette was analyzed for Cr, Ni and Mn, the other cassette was analyzed for Cr6.

Ventilation measurements, welding process, electrode type, etc. were recorded in the WFD which is presented in **Attachment B**. Where permitted, digital cameras were used to record the welding process under observation. All photographs were screened for acceptance by the shipyard contact person prior to departure of DynCorp from the site. Some of the photographs which were taken are presented in **Attachment D**.

Several of the participating shipyards provided DynCorp with welding fume air sample collection data from their records. Their data was entered into a separate database which is presented in **Attachment C**.

Graphs of information collected in the WFD are presented in **Attachment E**.

5.0 Conclusions & Recommendations

Current shipyard work, as observed, involveed the application of only limited special equipment and practices to control employee welding fume exposures. There were several engineering control methods available which could greatly reduce welders exposure to welding fumes, but no one control method was observed to consistently reduce worker exposures to levels below the lowest anticipated OSHA PEL reductions for Cr6 and Mn, 0.05 ug/m3 and 200 ug/m3, respectively. The current engineering controls observed during the Field Evaluations did not provide any one universally acceptable solution to controlling welding fume exposure, primarily due to the wide variety of materials and environments encountered in shipyard welding. A combination of current engineering controls would help to reduce worker fume exposure levels, but effective use of personal protective equipment still appears necessary to provide adequate protection.

A reduction in the OSHA PEL for welding fumes may result in new technological innovations for welding fume engineering controls. Welding equipment vendors who were contacted indicated that increased market demand for such products would stimulate them to dedicate additional resources for research and development of engineering control solutions.

Based upon observations from the Field Evaluation, DynCorp recommends the following:

1. Shipyards should consider the need to reduce fume exposures during the initial design phase of a ship construction project. This would include specifying materials that contain low levels of chrome and reducing or eliminating the use of welding processes that generate large amounts of fume.

2. Existing fume extraction systems should be reevaluated to determine if their design and operation can be improved for wider acceptability and application. Input from welders should be solicited.

3. Workers should be carefully trained to use fume extraction equipment properly. Supervisors should be trained to evaluate employee performance based upon the employee's demonstrated ability to use the equipment properly and consistently.

4. An industry standard should be established for classification of Low Fume Welding Wires.

5. Each shipyard visited made respirators available to their welders, but welders were consistently observed either not using the respirators or using respirators equipped with filters which were not designed to capture fumes. Proper selection and use of respirators should be a regular part of employee training and evaluation.

Task 3

Attachment A

Fume Study Main Data Entry

Date	______________
Investigator	______________
Welder	______________
Location	______________
Identifier	______________
Process	______________
AWS Elect Wire Class	______________
Electrode Brand	______________
Electrode Designation	______________
Electrode Diameter	______________
Base Metal Spec	______________
Surface Metal Cond	______________
Joint Designation	______________
Gas Shielding	______________
Flow Rate - CFH	______________
Welding Position	______________
Room Size - Sq Ft	______________
Ceiling Height - Ft	______________
Engineering Controls	______________
Exh Ventilation to Weld Pool (ft.)	______________
Fume Filtration	______________
Capture Velocity	______________
Fan Blower - CFM	______________
Fan Blower - HP	______________
Ventilation Direction	______________
Other Env Conditions	______________
Travel Speed - I/M	______________
Wire Feed Speed - I/M	______________
Wire Stick Out	______________
Est Arc Time	______________
Other	______________
Helmet Type	______________
Test Type	______________
Helmet to Arc	______________
Sampling Location	______________
Cr6 Pump #	______________
Cr6 Filter Type/Material/Pore Size	______________
Cr6 Sample Rate	______________
Cr6 Sample Time (Min)	______________
Cr6 Sample #	______________
Cr6 Results (ug/m3)	______________
Cr6 TWA (ug/m3)	______________
Welding Fume Pump #	______________
WF Filter Type/Material/Pore Size	______________
WF Sampling Rate	______________
WF Sample Time (Min)	______________
WF Sample #	______________
WF Cr Results (ug/m3)	______________
Cr TWA (ug/m3)	______________
WF Ni Results (ug/m3)	______________
Ni TWA (ug/m3)	______________
WF Mn Results (ug/m3)	______________

Task 3

Attachment B

Field	Date	Investigator	Welder	Location	Identifier	Process	AWS Elect Wire Class
5	09/22/1997	James W. Pettv	Worker AA	NORSHIPCO.	Shipvard A	SMAW - Shielded Metal Arc Weldina	AWS A5.5
6	09/22/1997	James W. Pettv	Worker AB	NORSHIPCO.	Shipvard A	FCAW - Flux Cored Arc Weldina	AWS A5.20
7	09/22/1997	James W. Pettv	Worker AC	NORSHIPCO.	Shipvard A	SMAW - Shielded Metal Arc Weldina	AWS A5.5
8	09/23/1997	James W. Pettv	Worker AD	NORSHIPCO.	Shipvard A	FCAW - Flux Cored Arc Weldina	AWS A5.20
9	09/23/1997	James W. Pettv	Worker AE	NORSHIPCO.	Shipvard A	GMAW - Gas Metal Arc Weldina	ER705-6
10	09/23/1997	James W. Pettv	Woeker AF	NORSHIPCO.	Shipvard A	FCAW - Flux Cored Arc Weldina	AWS A5.20
12	10/22/1997	Brad Christ	Worker BA	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS A5.20
13	10/22/1997	Brad Christ	Worker BB	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS A5.20 & ASME SFA-5.20
14	10/22/1997	Brad Christ	Worker BC	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS 5.20 & ASME SEA - 5.20
18	10/23/1997	Brad Christ	Worker BD	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS A5.20 & ASME SEA-5.20
19	10/23/1997	Brad Christ	Worker BE	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS A5.20 & ASME SEA-5.20
20	10/23/1997	Brad Christ	Worker BF	Lakeshore -	Shipvard B	FCAW - Flux Cored Arc Weldina	AWS A5.20 & ASME SEA-5.20
24	01/27/1998	Douglas H. Steil	Worker CA	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
26	01/27/1998	Douglas H. Steil	Worker CB	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
27	01/27/1998	Douglas H. Steil	Worker CC	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.22-80
28	01/27/1998	Douglas H. Steil	Worker CD	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
29	01/27/1998	Douglas H. Steil	Worker CE	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.22-80
30	01/28/1998	Douglas H. Steil	Worker CF	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
31	01/28/1998	Douglas H. Steil	Worker CG	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
32	01/28/1998	Douglas H. Steil	Worker CH	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
33	01/28/1998	Douglas H. Steil	Worker CI	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.22-80
34	01/28/1998	Douglas H. Steil	Worker CJ	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
35	01/28/1998	Douglas H. Steil	Worker CK	NASSCO - San	Shipvard C	FCAW - Flux Cored Arc Weldina	AWS A5.20-95
39	02/10/1998	Brad Christ	Worker DA	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
40	02/10/1998	Brad Christ	Worker DB	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
41	02/10/1998	Brad Christ	Worker DC	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
42	02/10/1998	Brad Christ	Worker DD	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
43	02/10/1998	Brad Christ	Worker DE	Alabama	Shipvard D	SMAW - Shielded Metal Arc Weldina	AWS A5.5
44	02/10/1998	Brad Christ	Worker DF	Alabama	Shipvard D	SMAW - Shielded Metal Arc Weldina	AWS A5.1
46	02/11/1998	Douglas H. Steil	Worker DG	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
47	02/11/1998	Douglas H. Steil	Worker DH	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
49	02/11/1998	Douglas H. Steil	Worker DI	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
50	02/11/1998	Douglas H. Steil	Worker DJ	Alabama	Shipvard D	SMAW - Shielded Metal Arc Weldina	AWS A5.5
51	02/11/1998	Douglas H. Steil	Worker DK	Alabama	Shipvard D	FCAW - Flux Cored Arc Weldina	AWS A5.20
52	02/12/1998	Brad Christ	Worker EA	Ingalls	Shipvard E	GTAW - Gas Tunasten Arc Weldina	N/A
53	02/12/1998	Brad Christ	Worker EB	Ingalls	Shipvard E	GMAW - Gas Metal Arc Weldina	SFA 5.10
54	02/12/1998	Brad Christ	Worker EC	Ingalls	Shipvard E	GMAW - Gas Metal Arc Weldina	SFA 5.10
55	02/12/1998	Brad Christ	Worker ED	Ingalls	Shipvard E	GMAW - Gas Metal Arc Weldina	N/A
56	02/12/1998	Brad Christ	Worker EE	Ingalls	Shipvard E	GTAW - Gas Tunasten Arc Weldina	N/A
57	02/12/1998	Brad Christ	Worker EF	Ingalls	Shipvard E	GTAW - Gas Tunasten Arc Weldina	N/A
58	02/18/1998	Douglas H. Steil	Worker FA	Bath Iron	Shipvard F	GMAW - Gas Metal Arc Weldina	AWS A5.20
59	02/18/1998	Douglas H. Steil	Worker FB	Bath Iron	Shipvard F	GMAW - Gas Metal Arc Weldina	AWS A5.9/MIL-E-21562
60	02/18/1998	Douglas H. Steil	Worker FC	Bath Iron	Shipvard F	GMAW - Gas Metal Arc Weldina	AWS A5.9/MIL-E-21562
61	02/19/1998	Douglas H. Steil	Worker FD	Bath Iron	Shipvard F	FCAW - Flux Cored Arc Weldina	AWS A5.20
62	02/19/1998	Douglas H. Steil	Worker FE	Bath Iron	Shipvard F	GTAW - Gas Tunasten Arc Weldina	MIL-E-21562E
63	02/19/1998	Douglas H. Steil	Worker FF	Bath Iron	Shipvard F	GTAW - Gas Tunasten Arc Weldina	MIL-E-21562E

AWS Elect Wire Class	Electrode Brand	Electrode	Electrode	Base Metal	Surface Metal	Joint Designati
AWS A5.5	ESAB	E701B	0.125"	N/A	Ground	Multiple Fillet
AWS A5.20	ESAB Dual Shield II 71 Ultra	E71T1	0.045"	AWS A5.20	Ground	Multiple Fillet
AWS A5.5	ESAB	E7018	3/32"	Carbon Steel	Ground	Other
AWS A5.20	ESAB Dual Shield II 71 Ultra	E71T1	0.045"	N/A	Ground	Multiple Fillet
ER705-6	ESAB	Spool Arc 86	0.045"	N/A	Paint	Multiple Fillet
AWS A5.20	ESAB Dual Shield II 71 Ultra	E71T1	0.045"	Carbon Steel	Other	Other
AWS A5.20	The Lincoln Electric Co.	71M - Mig Wire	0.052"	ASTM	Ground	Fillet
AWS A5.20 & ASME SFA-5.20	The Lincoln Electric Co.	GMAW Mig wire	0.045"	ASTM	Ground	Fillet
AWS 5.20 & ASME SEA - 5.20	The Lincoln Electric Co.	71M	0.052"	ASTM	Ground	Fillet
AWS A5.20 & ASME SEA-5.20	The Lincoln Electric Co.	71M	0.052"	ASTM	Ground	Fillet
AWS A5.20 & ASME SEA-5.20	The Lincoln Electric Co.	71M	0.045"	ASTM	Ground	Fillet
AWS A5.20 & ASME SEA-5.20	The Lincoln Electric Co.	71M	0.052"	ASTM	Ground	Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.22-80	ESAB Shieldbright 316 ELC	E316L-T1	0.045"	ASTM	Clean	Multiple Fillet
AWS A5.20-95	Trimark	E71T1-C, TM771	0.052"	ASTM	Clean	Square butt joint
AWS A5.22-80	ESAB Shieldbright 316 ELC	E316L-T1	0.045"	ASTM	Clean	Multiple Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.20-95	Trimark	E71T1-C	0.052"	ABS	Clean	Pipe Joint
AWS A5.22-80	ESAB Shieldbright 316 ELC	E316L-T1	0.045"	ASTM	Clean	Multiple Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.20-95	ESAB Dual Shield II 71 Ultra	E71T1-C	0.045"	ABS	Blasted and	Multiple Fillet
AWS A5.20	Trimark 777	E71T1	0.045"	ABS	Valspar gray	Fillet Welds
AWS A5.20	Trimark 777	E71T1	0.045"	ABS	Valspar gray	Fillet Welds
AWS A5.20	Trimark 777	E71T1	0.052"	ABS	Valspar gray	Fillet/Butt
AWS A5.20	Trimark 777	E71T1	0.052"	ABS	Hempalin red	Fillet Welds
AWS A5.5	ESAB	E7018M	0.125"	ASTM	Ground surface	Fillet Welds
AWS A5.1	ESAB	E7018M	0.125"	ASTM	Galvanized	Fillet Welds
AWS A5.20	Trimark 777	E71T1	0.045"	ABS	Valspar gray	Fillet Welds
AWS A5.20	ESAB Dual Shield II 71 Ultra	E71T1	0.045"	ABS	Valspar gray	Fillet/Butt
AWS A5.20	Trimark 777	E71T1	0.052"	ABS	Hempalin red	Fillet/Butt
AWS A5.5	ESAB	Carbon-ER70S-2,	Carbon-3/32",	ASTM A53	Ground Bare Pipe	Fillet Welds
AWS A5.20	Trimark 777	E71T1	0.045"	ABS	Hempalin red	Fillet/Butt
N/A	Gulf Wire	316	0.125	ASTM	Bare aluminum	Fillet/Butt
SFA 5.10	Harris	0032	0.035	N/A	Ground surface	Fillet/Butt
SFA 5.10	Gulf Wire	N/A	0.045	Mild steel	Ground surface	Fillet/Butt
N/A	ESAB	Coreshield 15	0.035	Mild steel	Ground surface	Butt
N/A	Gulf Wire/Imperial	R-5556	3/32"	Aluminum	Ground surface	Butt
N/A	Gulf Wire	R-5556	5/32"	Aluminum	Ground Surface	Tack
AWS A5.20	Trimark	70S3	0.045"	MIl-S-	Red Primer	Fillet Welds
AWS A5.9/MIL-E-21562	Arcos Alloy	Stainless-309,316L,	0.035"	ASTM	Clean and Ground	Fillet/Butt
AWS A5.9/MIL-E-21562	Arcos Alloy	Stainless-309,316L,	0.035"	ASTM	Clean and Ground	Fillet/Butt
AWS A5.20	ESAB Dual Shield II 71 Ultra	E71T1	0.045"	MIL-S-	Red Primer	Fillet Welds
MIL-E-21562E	Arcos Alloys	RN67/813	0.045	MIL-C-15726F	Clean and Ground.	Fillet Welds
MIL-E-21562E	Arcos Alloys	RN67/813	3/32"	MIL-C-15726F	Clean and Ground.	Fillet Welds

Joint Designation	Gas Shielding	Flow	Welding Position	Room	Ceilin	Engineering Controls
Multiple Fillet Welds	N/A	N/A	All	1200	8	Portable Fume Extraction System
Multiple Fillet Welds	Argon and CO2	66	All	1200	8	Low Fume Welding Wires & Portable Fume Extraction Syste
Other	N/A	N/A	All	1200	8	Portable Fume Extraction System
Multiple Fillet Welds	N/A	N/A	All	18000	35	Low Fume Welding Wires
Multiple Fillet Welds	Ar & CO2 & O2	75	Horizontal	18000	35	Portable Fume Extraction System
Other	CO2	N/A	All	36	12	Low Fume Welding Wires & Portable Fume Extraction Syste
Fillet	CO2 & Flux Core	55	Horizontal	38400	60	Fume Extractor Guns
Fillet	CO2 & Flux Core	40	All	38400	60	Portable fume extraction system & general shop ventilation
Fillet	CO2 & Flux Core	50	All	38400	60	Fume Extractor Guns
Fillet	CO2 & Flux Core	55	Horizontal	38400	60	Fume Extractor Guns
Fillet	CO2 & Flux Core	40	All	38400	60	Portable fume extraction system & general shop ventilation
Fillet	CO2 & Flux Core	50	All	38400	60	Fume Extractor Guns
Multiple Fillet Welds	CO2 & Flux Core	40	Vertical and Overhead	81	4	Low Fume Welding Wires & Portable Fume Extraction Syste
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal, Vertical, and Overhead	Outside	N/A	Low Fume Welding Wires
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal	Outside	N/A	Low Fume Welding Wires
Square butt joint	CO2 & Flux Core	40	Flat Roll Position	100	30	Fixed Fume Extraction System
Multiple Fillet Welds	CO2 & Flux Core	45	Horizontal	600	30	Fixed Fume Extraction System
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal and Vertical	117	4.5	Low Fume Welding Wires & Portable Fume Extraction Syste
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal and Overhead	117	4	Low Fume Welding Wires & Portable Fume Extraction Syste
Pipe Joint	CO2 & Flux Core	150	Flat Roll Position	100	30	Fixed Fume Extraction System
Multiple Fillet Welds	CO2 & Flux Core	2	Horizontal and Overhead	Outside	N/A	Low Fume Welding Wires
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal and Overhead	Outside	N/A	Low Fume Welding Wires
Multiple Fillet Welds	CO2 & Flux Core	40	Horizontal and Overhead	Outside	N/A	Low Fume Welding Wires
Fillet Welds	CO2 & Flux Core	35	Vertical, Horizontal, and Overhead	30000	48	Low Fume Welding Wires & General Shop Ventilation
Fillet Welds	CO2 & Flux Core	35	Vertical, Horizontal, and Overhead	30000	48	Low Fume Welding Wires & General Shop Ventilation
Fillet/Butt	CO2 & Flux Core	30	Vertical and Horizontal	1800	8	Low Fume Welding Wires
Fillet Welds	CO2 & Flux Core	30	All	900	10	Low Fume Welding Wires & Portable Supply Air Ventilation
Fillet Welds	N/A	N/A	All	600	10	Portable Supply Air Ventilation
Fillet Welds	N/A	N/A	Horizontal & Vertical	600	10	Portable Supply Air Ventilation
Fillet Welds	C02 & Flux Core	35	Vertical & Overhead	3000	48	Low Fume Welding Wires & General Shop Ventilation
Fillet/Butt	C02 & Flux Core	35	All	3000	48	Low Fume Welding Wires & General Shop Ventilation
Fillet/Butt	C02 & Flux Core	35	All	300	8	Low Fume Welding Wires & Portable Supply Air Ventilation
Fillet Welds	N/A	N/A	All	600	10	Portable Supply Air Ventilation
Fillet/Butt	C02 & Flux Core	35	All	900	10	Low Fume Welding Wires & Portable Supply Air Ventilation
Fillet/Butt	Argon	30	Horizontal & Vertical	15400	15	Fixed fume extraction system & general shop ventilation
Fillet/Butt	Argon/CO2	30	Vertical	15400	15	Fixed fume extraction system & general shop ventilation
Fillet/Butt	Argon/CO2	30	Vertical	15400	15	Fixed fume extraction system & general shop ventilation
Butt	Argon/CO2	35	Horizontal & Vertical	60000	40	Portable fume extraction system & general shop ventilation
Butt	Argon	50	Horizontal & Vertical	60000	40	Portable fume extraction system & general shop ventilation
Tack	Argon	50	Horizontal & Vertical	60000	40	Portable fume extraction system & general shop ventilation
Fillet Welds	CO2 & O2	40-60	Horizontal	85000	40-50	Portable fume extraction system & general shop ventilation
Fillet/Butt	He & Ar	40-60	Horizontal, Vertical, and Overhead	11000	40	Portable fume extraction system & general shop ventilation
Fillet/Butt	He & Ar	40-60	All	11000	40	Portable fume extraction system & general shop ventilation
Fillet Welds	CO2 & O2	40-60	Horizontal	85000	40-50	Low Fume Welding Wires & Portable Fume Extraction Syste
Fillet Welds	Argon	40-60	Horizontal	11000	40	Portable fume extraction system & general shop ventilation
Fillet Welds	Argon	40-60	Horizontal	11000	40	Portable fume extraction system & general shop ventilation

Engineering Controls	Exh Ventilation	Fume	Capture	Fan Blower - CFM	Fan Blower - HP
Portable Fume Extraction System	12'	No	N/A	N/A	10
Low Fume Welding Wires & Portable Fume Extraction	12' to 15'	No	N/A	N/A	10
Portable Fume Extraction System	35'	No	N/A	N/A	10
Low Fume Welding Wires	N/A	No	N/A	N/A	N/A
Portable Fume Extraction System	20'	No	N/A	N/A	10
Low Fume Welding Wires & Portable Fume Extraction	3' to 4'	No	133	N/A	10
Fume Extractor Guns	0.5'	Yes	Adjustable	Variable upon demand	15
Portable fume extraction system & general shop ventilation	1' to 3'	No	N/A	N/A	3
Fume Extractor Guns	0.5'	Yes	Adjustable	Variable upon demand	15
Fume Extractor Guns	0.5'	Yes	Adjustable	Variable upon demand	15
Portable fume extraction system & general shop ventilation	1' to 3'	No	N/A	N/A	3
Fume Extractor Guns	0.5'	Yes	Adjustable	Variable upon demand	15
Low Fume Welding Wires & Portable Fume Extraction	1.5'	No	345	N/A	15
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Fixed Fume Extraction System	1.5'	No	3250	N/A	15
Fixed Fume Extraction System	0.5'	No	1039	N/A	15
Low Fume Welding Wires & Portable Fume Extraction	1.5'	No	3" - 1890, 6" -	N/A	15
Low Fume Welding Wires & Portable Fume Extraction	3" to 1'/6" to 3'	No	3" - 1890, 6" -	N/A	15
Fixed Fume Extraction System	2'	No	3253	N/A	15
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Low Fume Welding Wires & General Shop Ventilation	48'	No	N/A	N/A	N/A
Low Fume Welding Wires & General Shop Ventilation	48'	No	N/A	N/A	N/A
Low Fume Welding Wires	N/A	N/A	N/A	N/A	N/A
Low Fume Welding Wires & Portable Supply Air Ventilation	None	No	N/A	33400	15
Portable Supply Air Ventilation	None	No	N/A	33400	15
Portable Supply Air Ventilation	None	N/A	N/A	33400	15
Low Fume Welding Wires & General Shop Ventilation	60'	No	N/A	N/A	10
Low Fume Welding Wires & General Shop Ventilation	60'	No	N/A	N/A	10
Low Fume Welding Wires & Portable Supply Air Ventilation	None	No	N/A	3000	2
Portable Supply Air Ventilation	None	No	N/A	33400	15
Low Fume Welding Wires & Portable Supply Air Ventilation	None	No	N/A	33400	15
Fixed fume extraction system & general shop ventilation	1'	No	1237	10000	7.5
Fixed fume extraction system & general shop ventilation	4'	No	160	10000	7.5
Fixed fume extraction system & general shop ventilation	5'	No	144	10000	7.5
Portable fume extraction system & general shop ventilation	6" to 12"	No	2080	10000	7.5
Portable fume extraction system & general shop ventilation	6" to 12"	No	3516	10000	7.5
Portable fume extraction system & general shop ventilation	6" to 12"	No	1733	10000	7.5
Portable fume extraction system & general shop ventilation	6" to 12"	No	1906	8000-10000	15
Portable fume extraction system & general shop ventilation	6" to 12"	No	1904	8000-10000	15
Portable fume extraction system & general shop ventilation	N/A	No	N/A	N/A	N/A
Low Fume Welding Wires & Portable Fume Extraction	6"	No	1276	8000-10000	15
Portable fume extraction system & general shop ventilation	10"	No	1567	8000-10000	15
Portable fume extraction system & general shop ventilation	N/A	No	N/A	N/A	N/A

Fan Blower - HP	Ventilation	Other Env Conditions	Travel Speed -	Wire Feed Speed -	Wire Stick	Est Arc
10	Horizontal	Sunshine, 60-70 degrees F	N/A	N/A	N/A	25% to 35%
10	Horizontal	Sunshine, 60 -70 degrees F	N/A	N/A	1/2-3/4"	25% to 35%
10	Horizontal	Sunshine, 60-70 degrees F	N/A	N/A	N/A	25% to 35%
N/A	N/A	Sunshine, 60-70 degrees F	N/A	N/A	1/2-3/4"	35%
10	Horizontal	Sunshine, 60-70 degrees F	N/A	N/A	1/2-3/4"	30% to 35%
10	Horizontal	Sunshine, 60-70 degrees F	N/A	N/A	1/2-3/4"	50%
15	Nozzle	Shop temp = mid 50's F,& Outside =	8	250-425	0.25"	35%
3	Horizontal	Shop temp = mid 50's F & Outside =	8	300	0.25"	15% to 20%
15	Nozzle	Shop temp = mid 50's F & Outside =	10	240-320	0.75"	20% to 30%
15	Nozzle	Shop temp = mid 50's F & Outside =	8	250-425	0.25"	35%
3	Horizontal	Shop temp = mid 50's F & Outside =	8	300	0.25"	10%
15	Nozzle	Shop temp = mid 50's F & Outside =	10	240-320	0.75"	20% to 30%
15	Overhead	Sunshine, 60-70 degrees F	8-14	300-400	5/8"	25% to 35%
N/A	N/A	Sunshine, 60-70 degrees F	5-14	300-400	1/2-5/8"	25% to 35%
N/A	N/A	Sunshine, 60-75 degrees F	8-14	300-400	1/2-5/8"	20%
15	N/A	Sunshine, 60-70 degrees F	5-14	200-300	1/2-5/8"	25%
15	Overhead	Sunshine, 60-75 degrees F	8-14	300-400	1/2-5/8"	20% to 25%
15	Overhead	Sunshine, 60-70 degrees F	5-14	350-450	1/2-5/8"	25% to 30%
15	Overhead	Sunshine, 60-75 degrees F	5-14	350-400	1/2-5/8"	20%
15	Overhead	Sunshine, 60-70 degrees F	5-14	300-400	1/2-5/8"	20%
N/A	N/A	Sunshine, 60-70 degrees F	5-14	300-400	1/2-5/8"	30% to 35%
N/A	N/A	Sunshine, 60-75 degrees F	5-14	300-400	1/2-5/8"	35% to 40%
N/A	N/A	Sunshine, 60-75 degrees F	5-14	300-400	1/2-5/8"	30% to 35%
N/A	Overhead	Indoors, 60-70 degrees F	12-14	315	3/4"	25% to 30%
N/A	Overhead	Indoors, 60-70 degrees F	12-14	315	3/4"	25% to 30%
N/A	Horizontal	Indoors, 60-70 degrees F	12-14	315	3/4"	30% to 35%
15	Horizontal	Indoors, 60-70 degrees F	12-14	315	3/4"	20%
15	Horizontal	Indoors, 60-70 degrees F	12-14	N/A	N/A	25% to 30%
15	Horizontal	Indoors, 60-70 degrees F	12-14	N/A	N/A	10% to 20%
10	Overhead	Indoors, 60-70 degrees F	12-14	315	3/4"	25% to 30%
10	Overhead	Indoors, 60-70 degrees F	12-14	315	3/4"	25%
2	Horizontal	Indoors, 60-70 degrees F	12-14	320	3/4"	25%
15	Horizontal	Indoors, 60-70 degrees F	12-14	N/A	N/A	30% to 35%
15	Horizontal	Indoors, 60-70 degrees F	12-14	320	3/4"	25% to 30%
7.5	Horizontal	Indoors, 55-60 degrees F	12-18	N/A	N/A	10%
7.5	Overhead	Indoors, 55-60 degrees F	8	350	1/2"	5%
7.5	Overhead	Indoors, 55-60 degrees F	18	150-300	1/2"	20% to 25%
7.5	Horizontal	Indoors, 55-60 degrees F	18	300	1/2"	20% to 25%
7.5	Horizontal	Indoors, 55-60 degrees F	12	100	3/4"	20% to 25%
7.5	Horizontal	Indoors, 55-60 degrees F	24	N/A	N/A	20% to 25%
15	Variable	Shop temp = 65-70 degrees F	16-24	300	3/4"	25% to 35%
15	Variable	Shop temp = 65-70 degrees F	12-24	270	3/8"	25% to 35%
N/A	N/A	Shop temp = 65-70 degrees F	12-24	270	3/8"	10% to 20%
15	Variable	Shop temp = 65-70 degrees F	12-14	255	1/32"	25% to 35%
15	Variable	Shop temp = 65-70 degrees F	12-24	306	3/8"	25% to 35%
N/A	N/A	Shop temp = 65-70 degrees F	4-6	6	0-3/8"	25% to 35%

Est Arc	Other	Helmet	Test Type	Helm	Sampling Location	Cr6 Pump
25% to 35%	Bulkhead welding inside ship	Full Face	Personal	1.5'	Ship - Deck 2, laundry room	Dyn-148
25% to 35%	Bulkhead welding inside ship	Full Face	Personal	1.5'	Ship - Deck 2, laundry room	4773
25% to 35%	Bulkhead welding inside ship	Full Face	Personal	1.5'	Ship - Deck 2, Section 2B	6336
35%	Bulkhead fabrication	Full Face	Personal	1.5'	Building 620 - Welding Shop	EMS-138
30% to 35%	General fabrication	Full Face	Personal	1.5'	Building 619 - Plate Shop	Dyn-148
50%	Small tasks	Full Face	Personal	1.5'	Building 620 - Welding Shop	Dyn-144
35%	Mild steel - hydraulic jig	Full Face	Personal	1.0'	S.E. quadrant of shop	LV-13
15% to 20%	Mild steel - Timberline beam	Full Face	Personal	1.0'	S.E. quadrant of shop	LV-12
20% to 30%	Mild steel - Inside barge hull	Full Face	Personal	1.0'	S.E. quadrant of shop	LV-15
35%	Mild steel - hydraulic jig	Full Face	Personal	1.0'	S.E. quadrant of shop	LV-15
10%	Mild steel - Timberline beam	Full Face	Personal	1.0'	S.E. quadrant of shop	LV-14
20% to 30%	Mild steel - Inside barge hull	Full Face	Personal	1.5'	S.E. quadrant of shop	LV-13
25% to 35%	4 hrs. inside bottom unit, 4 hrs. outside, 16.5 lbs wire	Full Face	Personal	1.5'	Assembly area (Bottom of	4773
25% to 35%	Mild steel, outside next to 29" tall bulkhead, 15 lbs.	Full Face	Personal	1.5'	Assembly deck with shell unit	Dyn-145
20%	2 hrs. stainless, remainder mild steel, 4 lbs. wire	Full Face	Personal	1.5'	Plate shop sub assembly	11377
25%	Welding booth, stainless and mild steel	Short	Personal	1.5'	Pipe Shop - Weld Booth	Dyn-148
20% to 25%	Stainless steel ductwork, 8 lbs wire	Full Face	Personal	1.5'	Sheet Metal Shop	11381
25% to 30%	Mild steel, inside bottom unit, 20 lbs wire	Full Face	Personal	1.5'	Assembly inner bottom # 023	11377
20%	Mild steel, inside bottom unit, 14 lbs wire	Full Face	Personal	1.5'	Assembly area, inner bottom	11380
20%	Welding booth, stainless and mild steel, 1.5 lbs wire	Full Face	Personal	1.5'	Pipe Shop - Weld Booth	4774
30% to 35%	Stainless steel turbine intakes, 25 lbs wire	Full Face	Personal	1.5'	Plate Shop, Bay 55 to 57	11381
35% to 40%	Mild steel, outside next to 36" bulkhead, 28 lbs wire	Full Face	Personal	1.5'	Assembly Area, Panel Line	EMS-138
30% to 35%	Mild steel, outside bext to 36" bulkhead, 25 lbs wire	Full Face	Personal	1.5'	Assembly Area, Panel Line	4771
25% to 30%	Open top fixture - deckhouse fabrication	Full Face	Personal	2'	Profile Shop - deckhouse	Dyn-145
25% to 30%	Welding inside open top deckhouse fixture	Full Face	Personal	2'	Profile Shop - deckhouse	EMS-138
30% to 35%	Inside A deck, on lowest level	Full Face	Personal	2'	A - Deck, Level 1	4773
20%	Portable supply ventilation hoses, flow rate = 0-70 fpm	Full Face	Personal	2'	Ship-Eng rm, bottom level	4796
25% to 30%	Portable supply ventilation hoses, flow rate = 507 fpm	Full Face	Personal	1.5'	Ship- Eng rm level 2 (lower	11381
10% to 20%	Portable supply ventilation hoses, flow rate = 475 fpm	Full Face	Personal	2'	Ship-Eng rm, main deck	11378
25% to 30%	Inside open top deckhouse fixture	Full Face	Personal	2'	Profile Shop - deckhouse	4774
25%	Open antenna mast fixture	Full Face	Personal	2'	Plate Shop - Antenna mast	4796
25%	Portable supply ventilation hoses, flow rate = 4000	Full Face	Personal	2.5'	Ship - Foucsile Deck	11377
30% to 35%	Portable supply ventilation hoses, flow rate = 59 fpm	Full Face	Personal	1.5'	Ship - Engine room level 2	11381
25% to 30%	Portable supply ventilation hoses, flow rate = 1420	Full Face	Personal	2'	Ship - Coffer Dam & Engine	Dyn-144
10%	Overhead hood & adjustable 6" exhaust hose	Full Face	Personal	1'	Electrical Shop	4796
5%	Overhead hood	Short	Personal	1'	Panel Shop	N/A
20% to 25%	Overhead hood	Short	Personal	2'	Electrical Shop	11378
20% to 25%	General fabrication	Full Face	Personal	1.5'	Sheet Metal Shop	4772
20% to 25%	Ductwork fabrication	Short	Personal	1.5'	Sheet Metal Shop	4771
20% to 25%	Tack welds on aluminum ductwork	Full Face	Personal	2'	Sheet Metal Shop	Dyn-145
25% to 35%	Ceiling Fans and Wall exhaust fans	Full Face	Personal	6-12"	B-Bay	4796
25% to 35%	Ceiling Fans and Wall exhaust fans	Full Face	Personal	6-12"	Fabrication Area	4773
10% to 20%	Ceiling Fans and Wall exhaust fans	Full Face	Personal	2'	Fabrication Area	4772
25% to 35%	Ceiling Fans and Wall exhaust fans	Full Face	Personal	6-12"	B-Bay	11377
25% to 35%	TIG, Ceiling Fans and Wall exhaust fans	Full Face	Personal	1-2'	Tank Shop	11379
25% to 35%	TIG, Ceiling Fans and Wall exhaust fans	Full Face	Personal	2'	Tank Shop	11381

Cr6 Pump	Cr6 Filter Type/Material/Pore	Cr6	Cr6	Cr6 Sample	Cr6	Cr6 TWA	Welding	WF Filter Type/Material/Pore	WF
Dvn-148	37 mm/PVC Cassette/0.8 micron	2.0	435	JP092297-01	1.1	0.997	144	37 mm/MCEF Cassette/0.8	2.0
4773	37 mm/PVC cassette/ 0.8 micron	2.0	396	JP092297-03	2.8	2.31	1492	37 mm/MCEF Cassette/0.8	2.0
6336	37 mm/PVC cassette/ 0.8 micron	2.0	438	JP092297-02	3.96	3.614	1494	37 mm/MCEF Cassette/0.8	2.0
EMS-138	37 mm/PVC cassette/0.8 micron	2.0	370	JP092397-03	5.95	4.59	4772	37 mm/MCEF Cassette/0.8	2.0
Dvn-148	37 mm/PVC Cassette/0.8 micron	2.0	300	JP092397-02	1	0.63	140	37 mm/MCEF Cassette/0.8	2.0
Dvn-144	37 mm/PVC cassette/0.8 micron	2.0	401	JP092397-01	0.59	0.493	4773	37 mm/MCEF Cassette/0.8	2.0
LV-13	37 mm/PVC Cassette/0.8 micron	2.0	480	CR102297-	0.29	0.29	LV-14	37 mm/MCEF Cassette/0.8	2.0
LV-12	37 mm/PVC Cassette/0.8 micron	2.0	485	CR102297-	0.61	0.6164	IH-14	37 mm/MCEF Cassette/0.8	2.0
LV-15	37 mm/PVC Cassette/0.8 micron	2.0	480	CR102297-	0	0	DYN-148	37 mm/MCEF Cassette/0.8	2.0
LV-15	37 mm/PVC Cassette/0.8 micron	2.0	405	CR102397-	0	0	LV-07	37 mm/MCEF Cassette/0.8	2.0
LV-14	37 mm/PVC Cassette/0.8 micron	2.0	385	CR102397-	1.2	0.963	LV-12	37 mm/MCEF Cassette/0.8	2.0
LV-13	37 mm/PVC Cassette/0.8 micron	2.0	400	CR102397-	0	0	DYN-148	37 mm/MCEF Cassette/0.8	2.0
4773	37 mm/PVC Cassette/0.8 micron	2.0	450	CR012798-	0.6	0.563	4772	37 mm/MCEF Cassette/0.8	2.0
Dvn-145	37 mm/PVC Cassette/0.8 micron	2.0	429	CR012798-	0	0	EMS-138	37 mm/MCEF Cassette/0.8	2.0
11377	37 mm/PVC Cassette/0.8 micron	2.0	427	CR012798-	0.81	0.721	11378	37 mm/MCEF Cassette/0.8	2.0
Dvn-148	37 mm/PVC Cassette/0.8 micron	2.0	424	CR012798-	0	0	11380	37 mm/MCEF Cassette/0.8	2.0
11381	37 mm/PVC Cassette/0.8 micron	2.0	415	CR012798-	1.5	1.3	11379	37 mm/MCEF Cassette/0.8	2.0
11377	37 mm/PVC Cassette/0.8 micron	2.0	465	CR012898-	0	0	11378	37 mm/MCEF Cassette/0.8	2.0
11380	37 mm/PVC Cassette/0.8 micron	2.0	460	CR012898-	0.79	0.757	11379	37 mm/MCEF Cassette/0.8	2.0
4774	37 mm/PVC Cassette/0.8 micron	2.0	445	CR012898-	0	0	4772	37 mm/MCEF Cassette/0.8	2.0
11381	37 mm/PVC Cassette/0.8 micron	2.0	425	CR012898-	3.23	2.86	DYN-145	37 mm/MCEF Cassette/0.8	2.0
EMS-138	37 mm/PVC Cassette/0.8 micron	2.0	419	CR012898-	1.1	0.96	4773	37 mm/MCEF Cassette/0.8	2.0
4771	37 mm/PVC Cassette/0.8 micron	2.0	410	CR012898-	0	0	4796	37 mm/MCEF Cassette/0.8	2.0
Dvn-145	37 mm/PVC Cassette/0.8 micron	2.0	480	CR021098-	0.34	0.34	DYN-144	37 mm/MCEF Cassette/0.8	2.0
EMS-138	37 mm/PVC Cassette/0.8 micron	2.0	470	CR021098-	0	0	9148	37 mm/MCEF Cassette/0.8	2.0
4773	37 mm/PVC Cassette/0.8 micron	2.0	475	CR021098-	0.72	0.71	11377	37 mm/MCEF Cassette/0.8	2.0
4796	37 mm/PVC Cassette/0.8 micron	2.0	480	CR021098-	0.49	0.49	4772	37 mm/MCEF Cassette/0.8	2.0
11381	37 mm/PVC Cassette/0.8 micron	2.0	475	CR021098-	0	0	4771	37 mm/MCEF Cassette/0.8	2.0
11378	37 mm/PVC Cassette/0.8 micron	2.0	503	CR021098-	0.49	0.51	11380	37 mm/MCEF Cassette/0.8	2.0
4774	37 mm/PVC Cassette/0.8 micron	2.0	410	CR021198-	0.3	0.26	4773	37 mm/MCEF Cassette/0.8	2.0
4796	37 mm/PVC Cassette/0.8 micron	2.0	475	CR021198-	0	0	4772	37 mm/MCEF Cassette/0.8	2.0
11377	37 mm/PVC Cassette/0.8 micron	2.0	465	CR021198-	0.59	0.57	11380	37 mm/MCEF Cassette/0.8	2.0
11381	37 mm/PVC Cassette/0.8 micron	2.0	480	CR021198-	0.79	0.79	11379	37 mm/MCEF Cassette/0.8	2.0
Dvn-144	37 mm/PVC Cassette/0.8 micron	2.0	480	CR021198-	0.82	0.82	Dvn-145	37 mm/MCEF Cassette/0.8	2.0
4796	37 mm/PVC Cassette/0.8 micron	2.0	380	CR021298-	0	0	4773	37 mm/MCEF Cassette/0.8	2.0
N/A	37 mm/PVC Cassette/0.8 micron	2.0	370	CR021298-	0	0	N/A	37 mm/MCEF Cassette/0.8	2.0
11378	37 mm/PVC Cassette/0.8 micron	2.0	425	CR021298-	0.8	0.71	11379	37 mm/MCEF Cassette/0.8	2.0
4772	37 mm/PVC Cassette/0.8 micron	2.0	402	CR021298-	0.55	0.46	11380	37 mm/MCEF Cassette/0.8	2.0
4771	37 mm/PVC Cassette/0.8 micron	2.0	365	CR021298-	0.9	0.68	9148	37 mm/MCEF Cassette/0.8	2.0
Dvn-145	37 mm/PVC Cassette/0.8 micron	2.0	398	CR021298-	0.6	0.498	4796	37 mm/MCEF Cassette/0.8	2.0
4796	37 mm/PVC Cassette/0.8 micron	2.0	463	CR021898-	0	0	11379	37 mm/MCEF Cassette/0.8	2.0
4773	37 mm/PVC Cassette/0.8 micron	2.0	445	CR021898-	3.36	3.24	11377	37 mm/MCEF Cassette/0.8	2.0
4772	37 mm/PVC Cassette/0.8 micron	2.0	427	CR022898-	3.42	3.17	11381	37 mm/MCEF Cassette/0.8	2.0
11377	37 mm/PVC Cassette/0.8 micron	2.0	484	CR021998-	0	0	11378	37 mm/MCEF Cassette/0.8	2.0
11379	37 mm/PVC Cassette/0.8 micron	2.0	457	CR021998-	0	0	4772	37 mm/MCEF Cassette/0.8	2.0
11381	37 mm/PVC Cassette/0.8 micron	2.0	452	CR021998-	0.56	0.53	4773	37 mm/MCEF Cassette/0.8	2.0

WF	WF	WF Sample	WF Cr Results	Cr TWA	WF Ni Results	Ni TWA	WF Mn Results
2.0	435	JP092297-04	3.1	2.8	2.3	2.08	44.7
2.0	396	JP092297-06	4.9	4	3.7	3.7	99.1
2.0	438	JP092297-05	0	0	0	0	85.4
2.0	370	JP092397-06	0	0	0	0	N/A
2.0	300	JP092397-05	0	0	0	0	N/A
2.0	401	JP092397-04	0	0	0	0	N/A
2.0	480	WF102297-	0	0	0	0	71.7
2.0	365	WF102297-	2.7	2.053	0	0	88.9
2.0	465	WF102297-	0	0	1.1	1.066	51.2
2.0	405	WF102397-	0	0	0	0	87.6
2.0	385	WF102397-	0	0	1.3	1.043	701
2.0	400	WF102397-	0	0	1.2	1	55.4
2.0	450	WF012798-	1.9	1.8	1.2	1	728
2.0	429	WF012798-	7	6.3	2	1.8	3110
2.0	427	WF012798-	40.7	36	14.8	13.1	350
2.0	424	WF012798-	0	0	0	0	7.9
2.0	415	WF012798-	89.3	77.2	20.2	17	167
2.0	465	WF012898-	15.6	10.7	3.8	2.6	6470
2.0	460	WF012898-	8.4	8.1	2.6	2.5	3420
2.0	445	WF012898-	0	0	0	0	7.9
2.0	425	WF012898-	198	175	40.9	36	253
2.0	419	WF012898-	6.2	5.4	0	0	2870
2.0	410	WF012898-	5.9	5	0	0	2590
2.0	480	WF021098-	2	2	0	0	393
2.0	470	WF021098-	2.1	2.06	0	0	165
2.0	475	WF021098-	2.3	2.28	0	0	947
2.0	480	WF021098-	2.4	2.4	2.1	2.1	314
2.0	475	WF021098-	4.6	4.55	9.8	9.7	448
2.0	503	WF021098-	1.1	1.15	0	0	87.7
2.0	475	WF021198-	3.9	3.86	0	0	1310
2.0	475	WF021198-	0	0	0	0	88.9
2.0	405	WF021198-	2.7	2.28	2	1.69	629
2.0	480	WF021198-	1.5	1.5	1.1	1.1	109
2.0	480	WF021198-	2.9	2.9	1.6	1.6	772
2.0	440	WF021298-	1.6	1.47	0	0	3.5
2.0	430	WF021298-	0	0	0	0	7.3
2.0	425	WF021298-	0	0	0	0	146
2.0	402	WF021298-	7.7	6.45	14.8	12.4	56
2.0	404	WF021298-	5	4.21	7.7	6.48	41.7
2.0	398	WF021298-	2.8	2.32	6.7	5.56	7.7
2.0	463	WF021898-	2	1.93	0	0	695
2.0	445	WF021898-	73	67.68	197	182.64	23.5
2.0	427	WF021898-	51.1	45.46	141	125.43	18.8
2.0	484	WF021998-	1.5	1.513	1.1	1.11	226
2.0	457	WF021998-	10.4	9.9	31	29.51	15.4
2.0	452	WF021998-	8	7.53	25.9	24.39	12.7

Task 3

Attachment C

Shipyard Location	Sample	Work Performed	Electrode	Helmet Type	Exhaust	Othe	Sampling Duration	Flow Rate
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		482	2.2
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		428	2.1
Shipyard F	Area	Welding of nickel	FN625 Arcos Alloy	N/A	N/A		450	2.16
Shipyard F	Area	Welding of nickel	FN625 Arcos Alloy	N/A	N/A		455	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		449	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		465	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		445	2.2
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		429	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		453	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		453	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		464	2.2
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		480	1.85
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		175	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		375	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		456	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		459	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		450	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		430	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		250	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.2
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		390	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		443	2.2
Shipyard F	Area	Welding of nickel	FN625 Arcos Alloy	N/A	N/A		445	2.0
Shipyard F	Area	Welding of nickel	FN625 Arcos Alloy	N/A	N/A		452	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		460	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		450	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		250	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		440	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		390	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		420	2.0
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		456	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		375	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		445	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		175	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		464	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		453	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		453	2.1
Shipyard F	Personal	Welding of nickel	FN625 Arcos Alloy	Welders Hood	N/A		429	2.1
Shipyard D	Personal	Welding of Mild	6010 & 7018 Stick	N/A	N/A		480	2.5
Shipyard D	Personal	Supervising	N/A	N/A	N/A		480	2.5
Shipyard D	Personal	General Cleaning	N/A	N/A	N/A		480	2.5
Shipyard D	Personal	Safety	N/A	N/A	N/A		480	2.5
Shipyard D	Personal	Pipe Welder	6010 & 7018 Stick	N/A	N/A		240	2.5
Shipyard D	Personal	Welder	6010 & 7018 Stick	N/A	N/A		480	2.5
Shipyard D	Personal	Welder	Flux Core Wire	N/A	N/A		480	2.5
Shipyard D	Personal	Shipfitter	6010 & 7018 Stick	N/A	N/A		480	2.5
Shipyard D	Personal	Welder	Flux Core Wire	N/A	N/A		480	2.5
Shipyard D	Personal	Pipefitter-Mild	N/A	N/A	N/A		480	2.5
Shipyard D	Personal	Welder-Carbon	Flux Core Wire	N/A	N/A		360	2.5
Shipyard D	Personal	Welder-Carbon	Flux Core Wire	N/A	N/A		360	2.5
Shipyard D	Personal	Shipfitter-Steel	7018 Stick Rods	N/A	N/A		480	2.5

Shipyard D	Personal	Shipfitter-Steel	6011 1/8" Stick	N/A	N/A		480	2.5
Shipyard D	Personal	Shipfitter-Tack	7018 Stick Rods	N/A	N/A		480	2.5
Shipyard D	Personal	Welder-Carbon	Flux Core Wire	N/A	N/A		480	2.5
Shipyard D	Personal	Pipefitter-Steel	N/A	N/A	N/A		480	2.5
Shipyard D	Personal	Welder-Carbon	Flux Core Wire	N/A	N/A		480	2.5
Shipyard D	Personal	Welder	Flux Core Wire	N/A	N/A		420	2.5
Shipyard C	Area	Stainless Steel	Flux-Cored Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Flux-Cored Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Flux-Cored Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A		N/A	N/A
Shipyard C	Area	Stainless Steel	Gas Tungsten Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Shielded Metal Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Shielded Metal Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Shielded Metal Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Shielded Metal Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Area	Stainless Steel	Shielded Metal Arc	N/A	N/A	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Flux-Cored Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A

Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	N/A	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Enclosed work	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Gas Tungsten Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area	Weld	N/A	N/A
Shipyard C	Personal	Welder-Stainless	Shielded Metal Arc	N/A	Open work area.	Weld	N/A	N/A
Shipyard E	Personal	Welder-Stainless	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Pulse arc welding	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Pulse arc welding	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Burning	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Surface Grinder	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Burning	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	Jack Hammer	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Personal	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shipyard E	Area	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Total Sampling	Cr6 Results	Cr6 TWA	Cr Results	Cr TWA	Ni Results	Ni TWA	Mn	Mn TWA
1060.4	2.2	2.21	N/A	N/A	N/A	N/A	N/A	N/A
898.8	0.96	0.86	N/A	N/A	N/A	N/A	N/A	N/A
972	0.07	0.066	N/A	N/A	N/A	N/A	N/A	N/A
955.5	0.04	0.038	N/A	N/A	N/A	N/A	N/A	N/A
898	0.51	0.48	N/A	N/A	N/A	N/A	N/A	N/A
976.5	0.78	0.76	N/A	N/A	N/A	N/A	N/A	N/A
979	0.22	0.20	N/A	N/A	N/A	N/A	N/A	N/A
900.9	0.5	0.45	N/A	N/A	N/A	N/A	N/A	N/A
951.3	0.6	0.57	N/A	N/A	N/A	N/A	N/A	N/A
951.3	1.3	1.23	N/A	N/A	N/A	N/A	N/A	N/A
1020.8	2.1	2.03	N/A	N/A	N/A	N/A	N/A	N/A
888	0	0	N/A	N/A	N/A	N/A	N/A	N/A
367.5	0.6	0.2	N/A	N/A	N/A	N/A	N/A	N/A
787.5	1.5	1.2	N/A	N/A	N/A	N/A	N/A	N/A
957.6	0.6	0.57	N/A	N/A	N/A	N/A	N/A	N/A
819	1.7	1.63	N/A	N/A	N/A	N/A	N/A	N/A
945	2.0	1.9	N/A	N/A	N/A	N/A	N/A	N/A
880	0.4	0.37	N/A	N/A	N/A	N/A	N/A	N/A
903	0.07	0.06	N/A	N/A	N/A	N/A	N/A	N/A
924	0.2	0.18	N/A	N/A	N/A	N/A	N/A	N/A
500	2.9	1.51	N/A	N/A	N/A	N/A	N/A	N/A
968	0.76	0.7	N/A	N/A	N/A	N/A	N/A	N/A
819	0.95	0.77	N/A	N/A	N/A	N/A	N/A	N/A
974.6	1.4	1.3	N/A	N/A	N/A	N/A	N/A	N/A
890	N/A	N/A	13	12.05	28	25.96	4.1	3.8
949.2	N/A	N/A	8.9	8.4	16	15.1	7.9	7.44
924	N/A	N/A	420	385	1410	1292.5	7.7	7.1
966	N/A	N/A	94	90.1	170	163	10	9.6
945	N/A	N/A	51	47.8	110	103.1	7.4	6.94
924	N/A	N/A	21	19.25	42	38.5	1.1	1.01
525	N/A	N/A	360	187.5	870	453.1	3.0	1.56
880	N/A	N/A	160	146.7	340	311.7	11	10.1
819	N/A	N/A	62	50.38	150	121.9	1.6	1.3
882	N/A	N/A	3.9	3.4	6.5	5.69	0.57	.50
957.6	N/A	N/A	81	76.95	140	133	16	15.2
787.5	N/A	N/A	410	320.3	1300	1015.6	4.6	3.59
934.5	N/A	N/A	43	39.86	88	81.6	2.2	2.04
367.5	N/A	N/A	170	62	430	156.8	3.4	1.24
974.4	N/A	N/A	120	116	320	309.3	4.6	4.45
951.3	N/A	N/A	120	113.25	170	160.4	44	41.5
951.3	N/A	N/A	140	132.1	390	368.1	3.2	3.02
900.9	N/A	N/A	120	107.25	300	268.1	6.1	5.45
1200	N/A	N/A	0.42	0.42	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.38	0.38	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.57	0.57	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.25	0.25	N/A	N/A	N/A	N/A
600	N/A	N/A	0.80	0.4	N/A	N/A	N/A	N/A
1200	N/A	N/A	16.3	16.3	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.50	0.50	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.54	0.54	N/A	N/A	N/A	N/A
1200	N/A	N/A	0	0	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.83	0.83	N/A	N/A	N/A	N/A
900	N/A	N/A	0.40	0.3	N/A	N/A	N/A	N/A
900	N/A	N/A	0.43	0.32	N/A	N/A	N/A	N/A

1200	N/A	N/A	0.65	0.65	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.48	0.48	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.40	0.40	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.50	0.5	N/A	N/A	N/A	N/A
1200	N/A	N/A	0.43	0.43	N/A	N/A	N/A	N/A
1200	N/A	N/A	1.10	1.10	N/A	N/A	N/A	N/A
1050	N/A	N/A	4.65	4.1	N/A	N/A	N/A	N/A
N/A	N/A	N/A	4100	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	3600	N/A	N/A	N/A	N/A	N/A
N/A	21	N/A	270	N/A	N/A	N/A	N/A	N/A
N/A	<5.0	N/A	<6.0	N/A	N/A	N/A	N/A	N/A
N/A	<3.0	N/A	<6.0	N/A	N/A	N/A	N/A	N/A
N/A	<1.0	N/A	<5.0	N/A	N/A	N/A	N/A	N/A
N/A	12.2	N/A	50.0	N/A	N/A	N/A	N/A	N/A
N/A	<1.0	N/A	<6.0	N/A	N/A	N/A	N/A	N/A
N/A	<1.0	N/A	<6.0	N/A	N/A	N/A	N/A	N/A
N/A	<2.0	N/A	8.0	N/A	N/A	N/A	N/A	N/A
N/A	34.6	N/A	800.0	N/A	N/A	N/A	N/A	N/A
N/A	<4.0	N/A	8.0	N/A	N/A	N/A	N/A	N/A
N/A	9.1	N/A	20.0	N/A	N/A	N/A	N/A	N/A
N/A	<8.0	N/A	40.0	N/A	N/A	N/A	N/A	N/A
N/A	28.5	N/A	380.0	N/A	N/A	N/A	N/A	N/A
N/A	<2.0	N/A	<7.0	N/A	N/A	N/A	N/A	N/A
N/A	4.0	N/A	10.0	N/A	N/A	N/A	N/A	N/A
N/A	<2.0	N/A	10.0	N/A	N/A	N/A	N/A	N/A
N/A	<2.0	N/A	<3.0	N/A	N/A	N/A	N/A	N/A
N/A	1100	N/A	3162	N/A	N/A	N/A	N/A	N/A
N/A	1300	N/A	3700	N/A	N/A	N/A	N/A	N/A
N/A	1490	N/A	3600	N/A	N/A	N/A	N/A	N/A
N/A	640	N/A	1250	N/A	N/A	N/A	N/A	N/A
N/A	860	N/A	1800	N/A	N/A	N/A	N/A	N/A
N/A	8.0	4.6	69.0	39.3	N/A	N/A	N/A	N/A
N/A	<0.4	<0.4	<0.9	<0.9	N/A	N/A	N/A	N/A
N/A	6.9	5.9	130.0	111.8	N/A	N/A	N/A	N/A
N/A	51.0	37.2	170.0	124.1	N/A	N/A	N/A	N/A
N/A	11.0	8.0	56.0	40.9	N/A	N/A	N/A	N/A
N/A	2.5	1.7	130.0	88.4	N/A	N/A	N/A	N/A
N/A	5.7	2.3	43.0	20.0	N/A	N/A	N/A	N/A
N/A	21.0	14.1	140.0	93.8	N/A	N/A	N/A	N/A
N/A	1.9	1.6	10.0	8.5	N/A	N/A	N/A	N/A
N/A	<2.0	<2.0	56.0	12.5	N/A	N/A	N/A	N/A
N/A	N/A	N/A	6.4	<2.0	N/A	N/A	N/A	N/A
N/A	6.8	7.1	55.0	57.2	N/A	N/A	N/A	N/A
N/A	4.3	4.4	78.0	80.3	N/A	N/A	N/A	N/A
N/A	1.9	1.4	19.0	13.5	N/A	N/A	N/A	N/A
N/A	0.4	0.3	32.0	25.6	N/A	N/A	N/A	N/A
N/A	<0.6	<0.6	6.0	3.4	N/A	N/A	N/A	N/A
N/A	N/A	N/A	18.0	14.0	N/A	N/A	N/A	N/A
N/A	<0.5	<0.5	5.3	4.3	N/A	N/A	N/A	N/A
N/A	N/A	N/A	<1.0	<1.0	N/A	N/A	N/A	N/A
N/A	<5.0	<5.0	4.0	3.5	N/A	N/A	N/A	N/A
N/A	N/A	N/A	3.0	2.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	<4.0	<4.0	N/A	N/A	N/A	N/A
N/A	0.4	0.3	6.0	4.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	10.0	5.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	4.0	2.1	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	8.0	3.0	N/A	N/A	N/A	N/A

N/A	<1.0	<1.0	3.0	2.2	N/A	N/A	N/A	N/A
N/A	<0.4	<0.4	<0.9	<0.9	N/A	N/A	N/A	N/A
N/A	12.0	8.3	31.0	21.4	N/A	N/A	N/A	N/A
N/A	6.8	6.0	20.0	17.6	N/A	N/A	N/A	N/A
N/A	N/A	N/A	10.4	6.7	N/A	N/A	N/A	N/A
N/A	7.0	5.0	19.0	13.9	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	<1.0	<1.0	N/A	N/A	N/A	N/A
N/A	<2.0	<2.0	<3.0	<3.0	N/A	N/A	N/A	N/A
N/A	<0.7	<0.7	10.9	7.7	N/A	N/A	N/A	N/A
N/A	<0.7	<0.7	8.0	3.4	N/A	N/A	N/A	N/A
N/A	<2.0	<2.0	<3.0	<3.0	N/A	N/A	N/A	N/A
N/A	<0.8	<0.8	10.0	7.3	N/A	N/A	N/A	N/A
N/A	<0.8	<0.8	2.0	1.6	N/A	N/A	N/A	N/A
N/A	0.4	0.3	3.0	2.0	N/A	N/A	N/A	N/A
N/A	1.0	0.8	10.0	7.6	N/A	N/A	N/A	N/A
N/A	0.4	0.3	3.0	2.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	<2.0	<2.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	74.0	59.9	N/A	N/A	N/A	N/A
N/A	<0.7	<0.7	4.0	3.1	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	26.0	13.0	N/A	N/A	N/A	N/A
N/A	<1.0	<1.0	58.0	15.7	N/A	N/A	N/A	N/A
N/A	<0.9	<0.9	2.0	1.3	N/A	N/A	N/A	N/A
N/A	<2.0	<2.0	10.0	3.3	N/A	N/A	N/A	N/A
N/A	<0.6	<0.6	5.0	3.6	N/A	N/A	N/A	N/A
N/A	<0.6	<0.6	5.0	2.7	N/A	N/A	N/A	N/A
N/A	3.2	1.8	20.0	11.0	N/A	N/A	N/A	N/A
N/A	19.0	7.0	29.0	10.7	N/A	N/A	N/A	N/A
N/A	3.2	1.8	20.0	11.0	N/A	N/A	N/A	N/A
N/A	19.0	7.0	29.0	10.7	N/A	N/A	N/A	N/A
N/A	39.0	33.0	110.0	90.0	N/A	N/A	N/A	N/A
N/A	<0.2	<0.2	32.0	11.0	N/A	N/A	N/A	N/A
N/A	21.0	15.0	63.0	44.0	N/A	N/A	N/A	N/A
N/A	71.0	20.6	160.0	46.4	N/A	N/A	N/A	N/A
N/A	14.0	11.3	54.0	43.7	N/A	N/A	N/A	N/A
N/A	74.7	59.0	180.0	142.2	N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	72	74	90	93	68	70
N/A	N/A	N/A	128	137	442	472	4.5	4.5
N/A	N/A	N/A	4.5	4.5	17	18	9	9
N/A	N/A	N/A	5	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	4.4	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	5	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	9	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	9	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	30	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	40	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	40	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	40	N/A	N/A	N/A	N/A	N/A
N/A	N/A	N/A	40	N/A	N/A	N/A	N/A	N/A

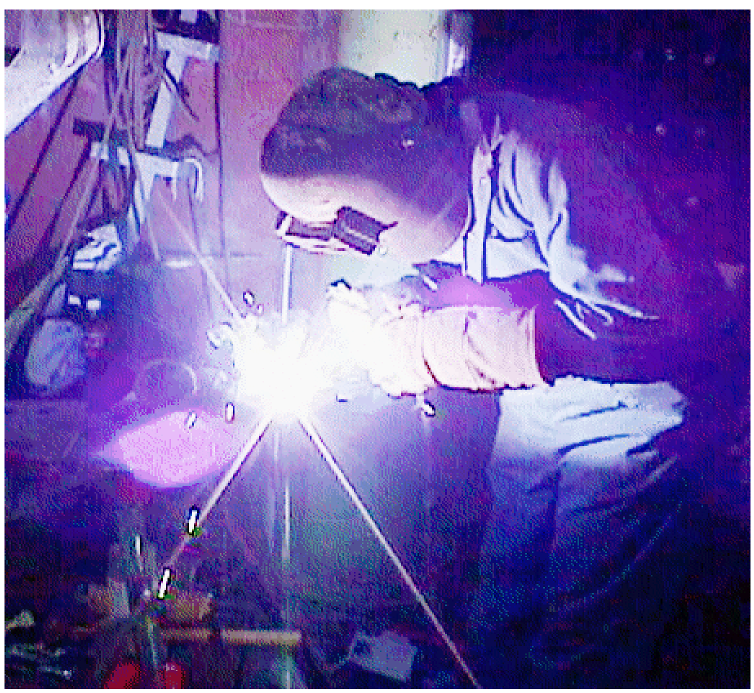
Task 3

Attachment D

Photograph 1. Industrial Hygienist collecting ventilation measurements from ventilator supply air hose in a ship engine room

Photograph 2. Industrial Hygienist collecting ventilation measurements from a large, portable fume extraction unit

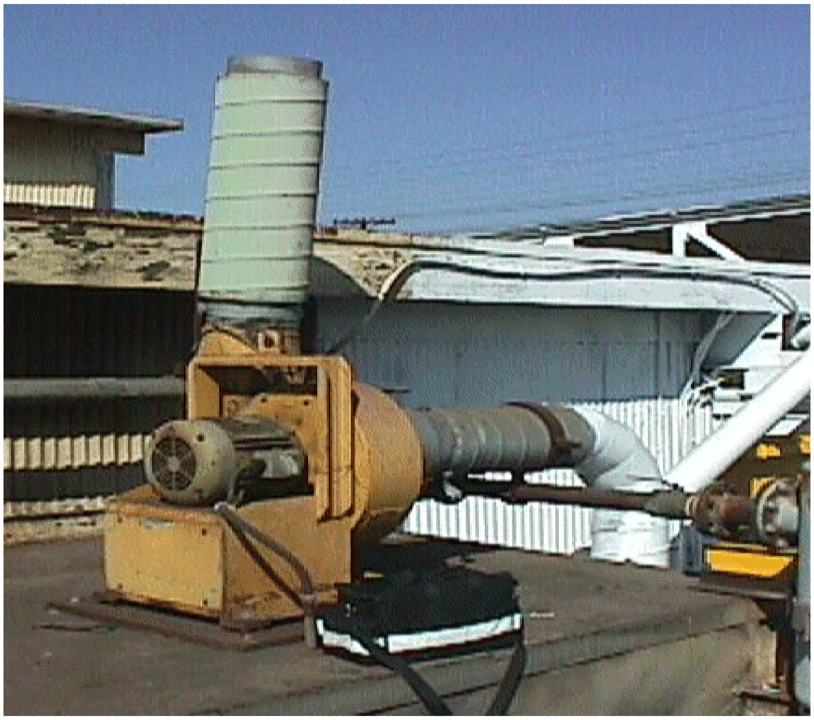
Photograph 3. Welder with air monitoring cassettes mounted on shirt collar



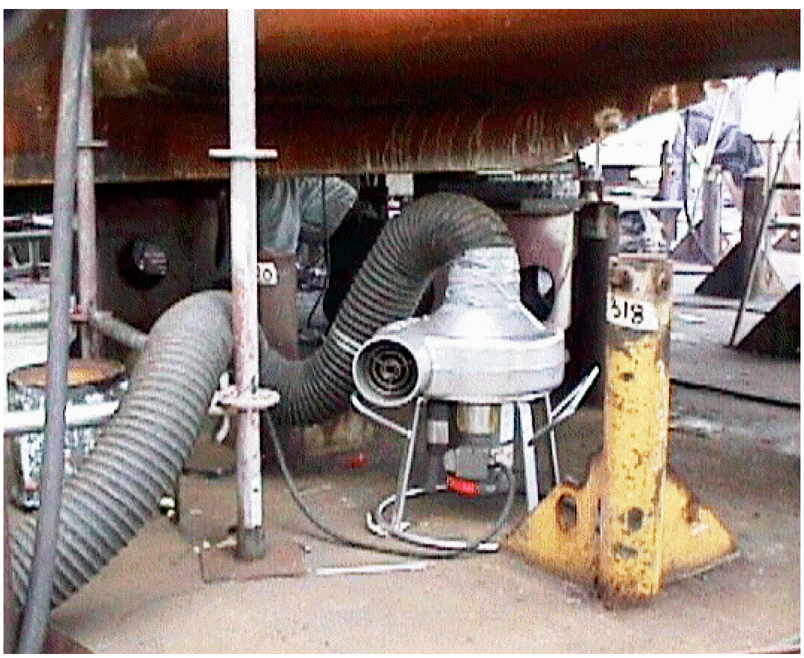
Photograph 4. Same welder as shown in Photograph 3 with welding helmet shielding the air sample cassettes

Photograph 5. Welder with air sample pumps affixed to worker's belt

Photograph 6. Fixed fume extractor system with moveable suction hose inside fabrication shop



Photograph 7. Roof mounted exhaust fan for fixed fume extraction system

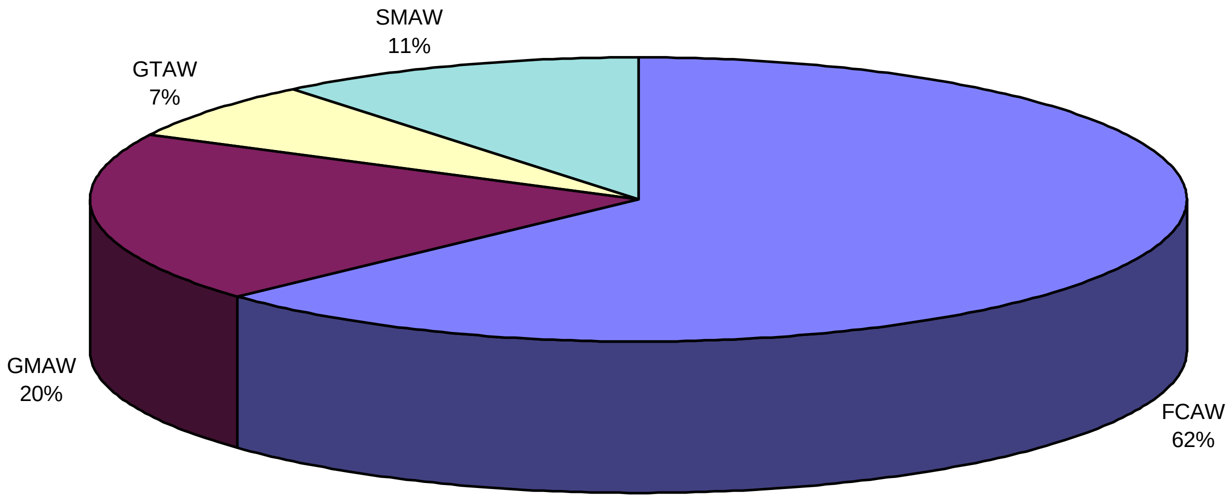


Photograph 8. Small, portable fume extraction ventilation blower being used to ventilate hull assembly

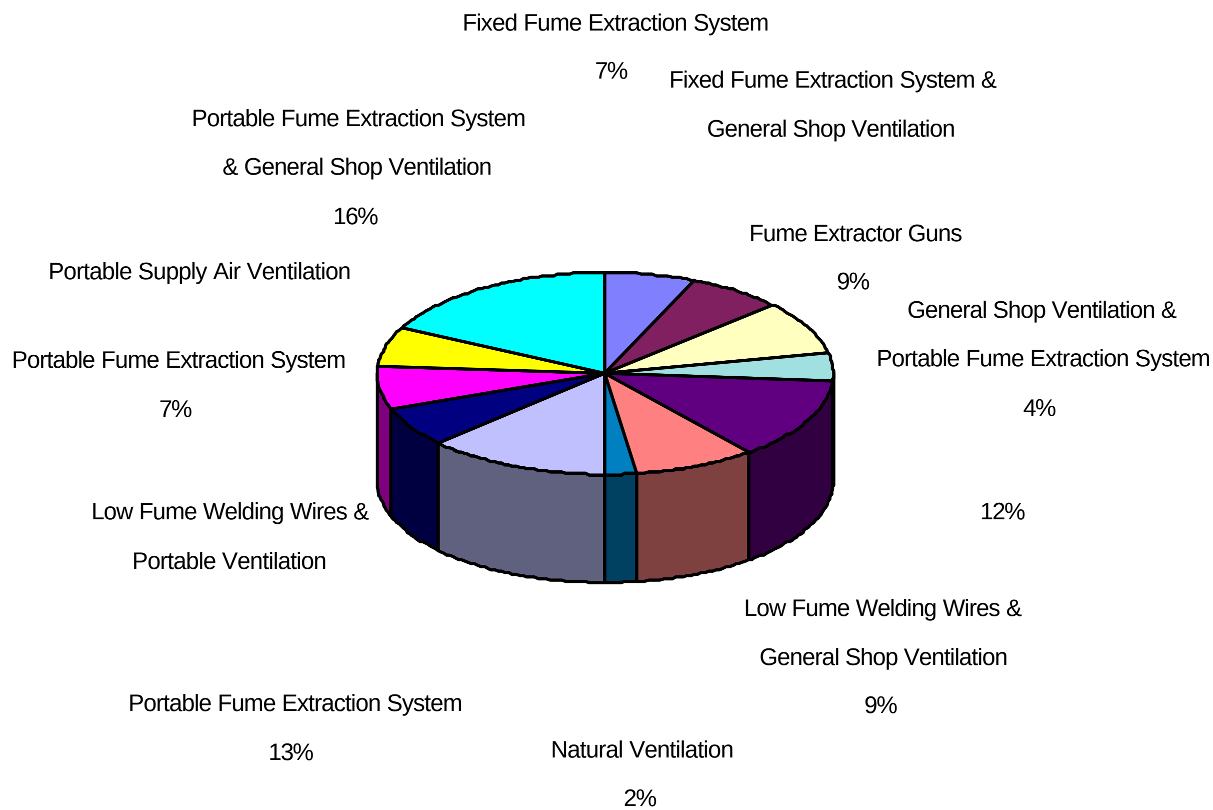
Task 3

Attachment E

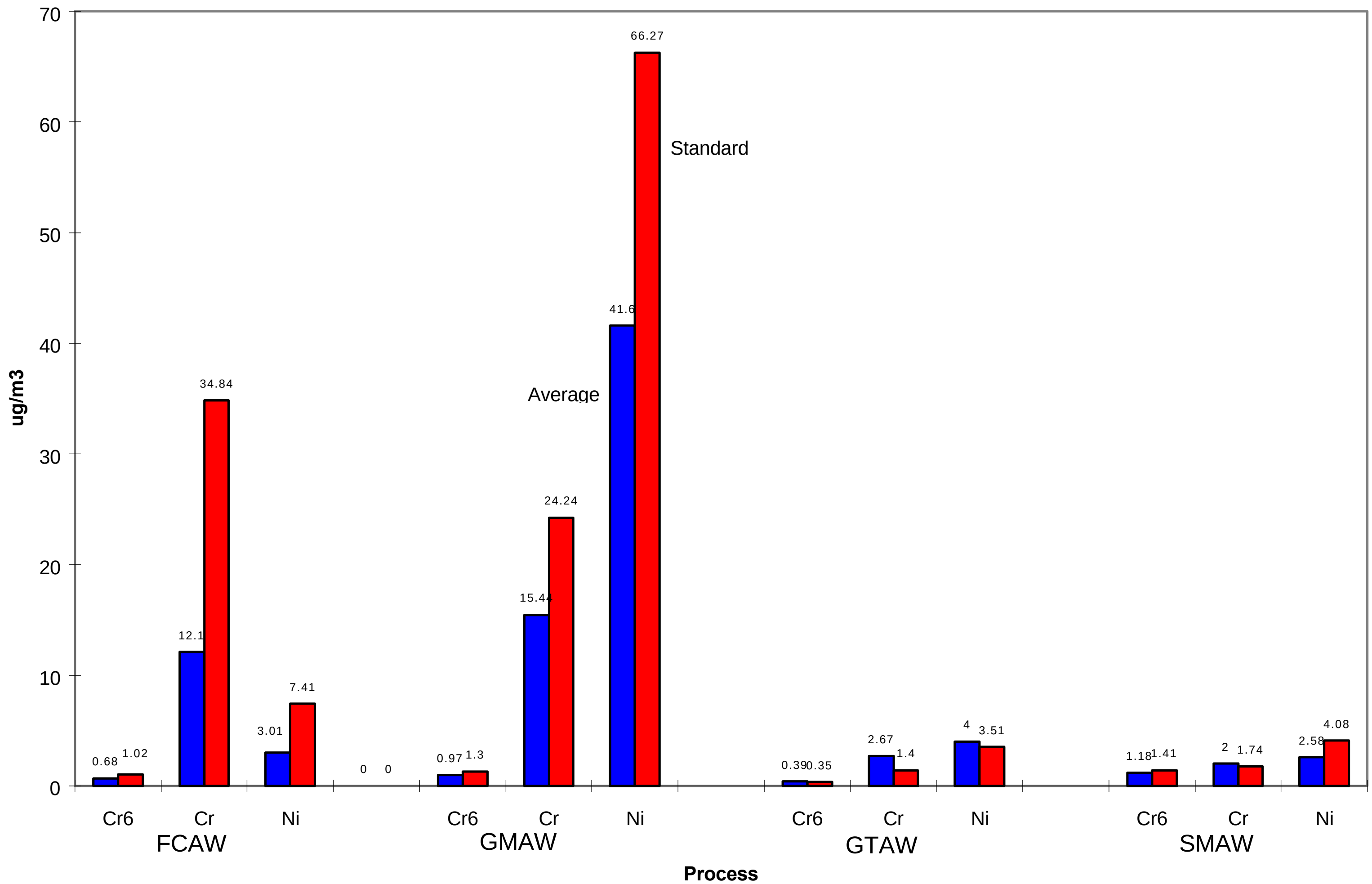
Number of Samples Collected by Process



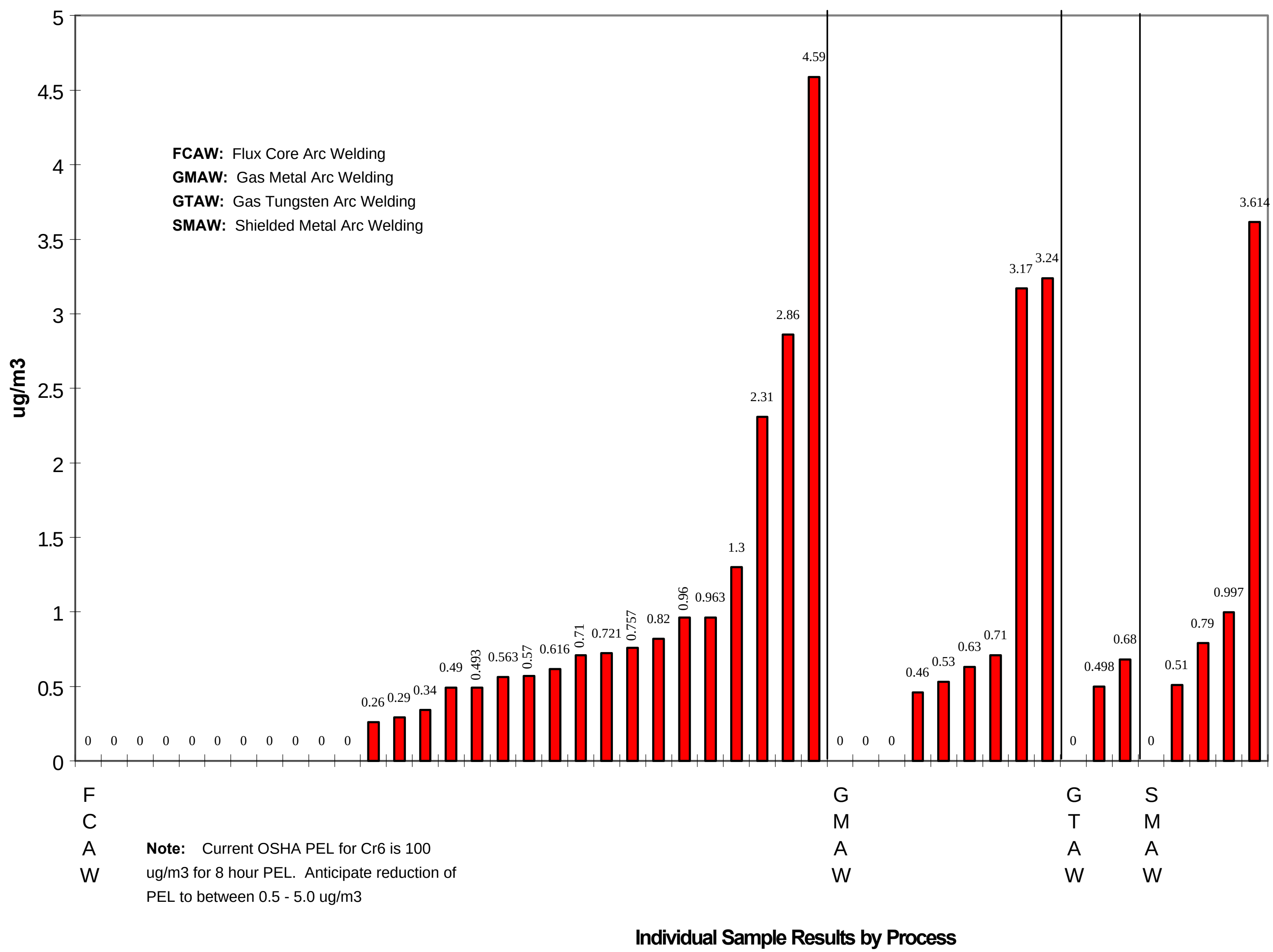
Number of Samples Collected by Engineering Control

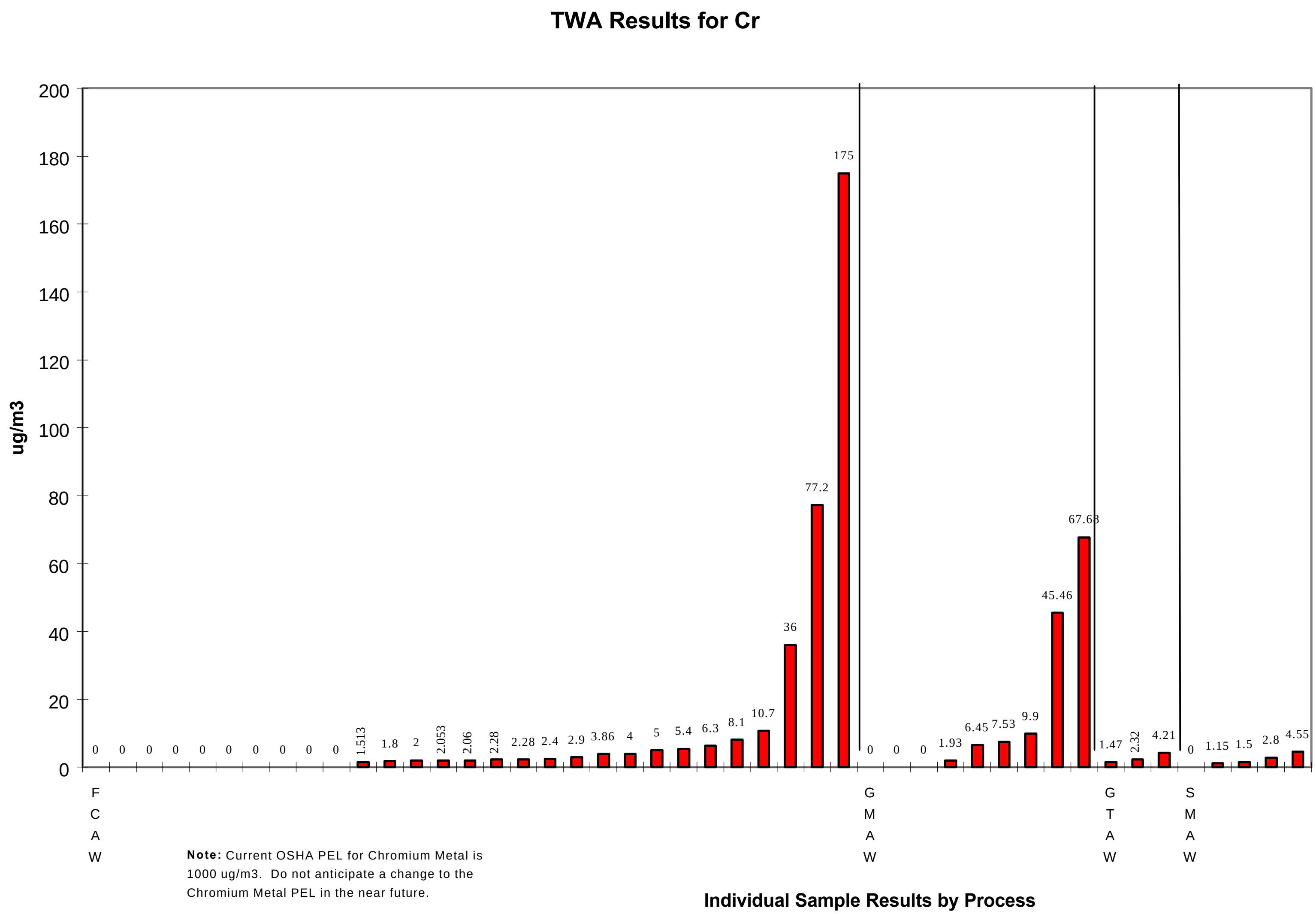


Average Contaminant Concentration by Process (Cr6, Cr, Ni)

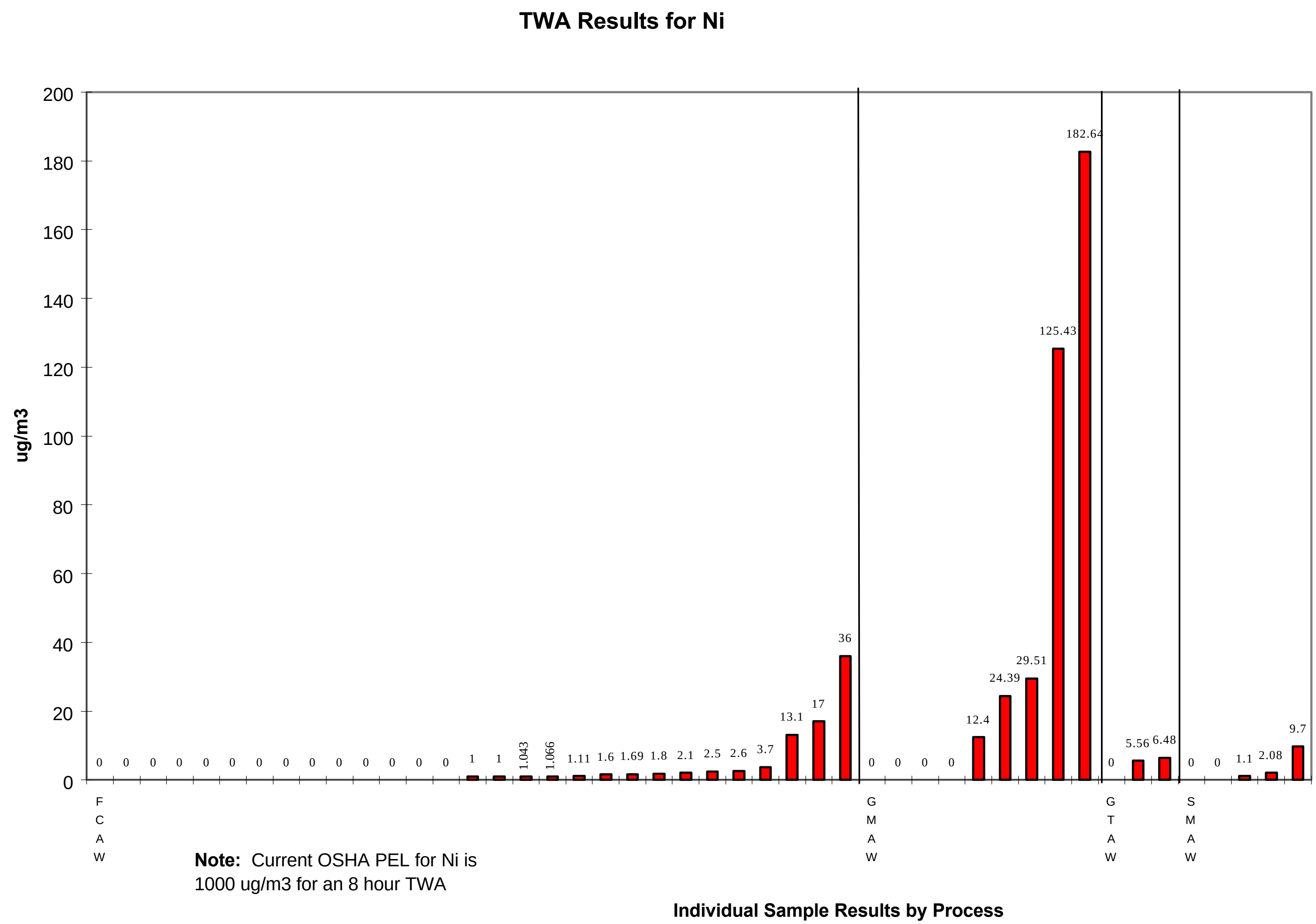


TWA Results for Cr6



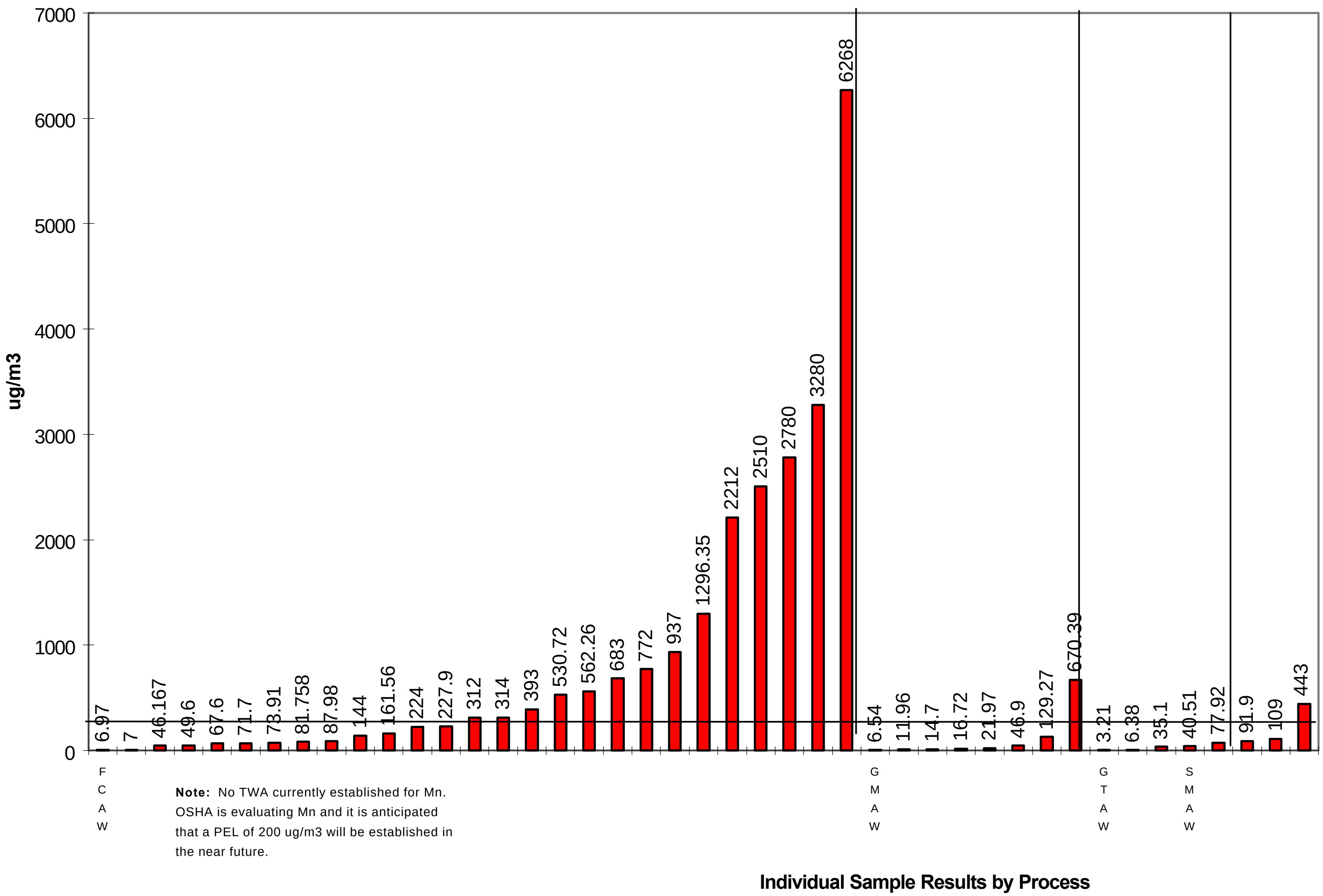


Note: Current OSHA PEL for Chromium Metal is 1000 ug/m3. Do not anticipate a change to the Chromium Metal PEL in the near future.

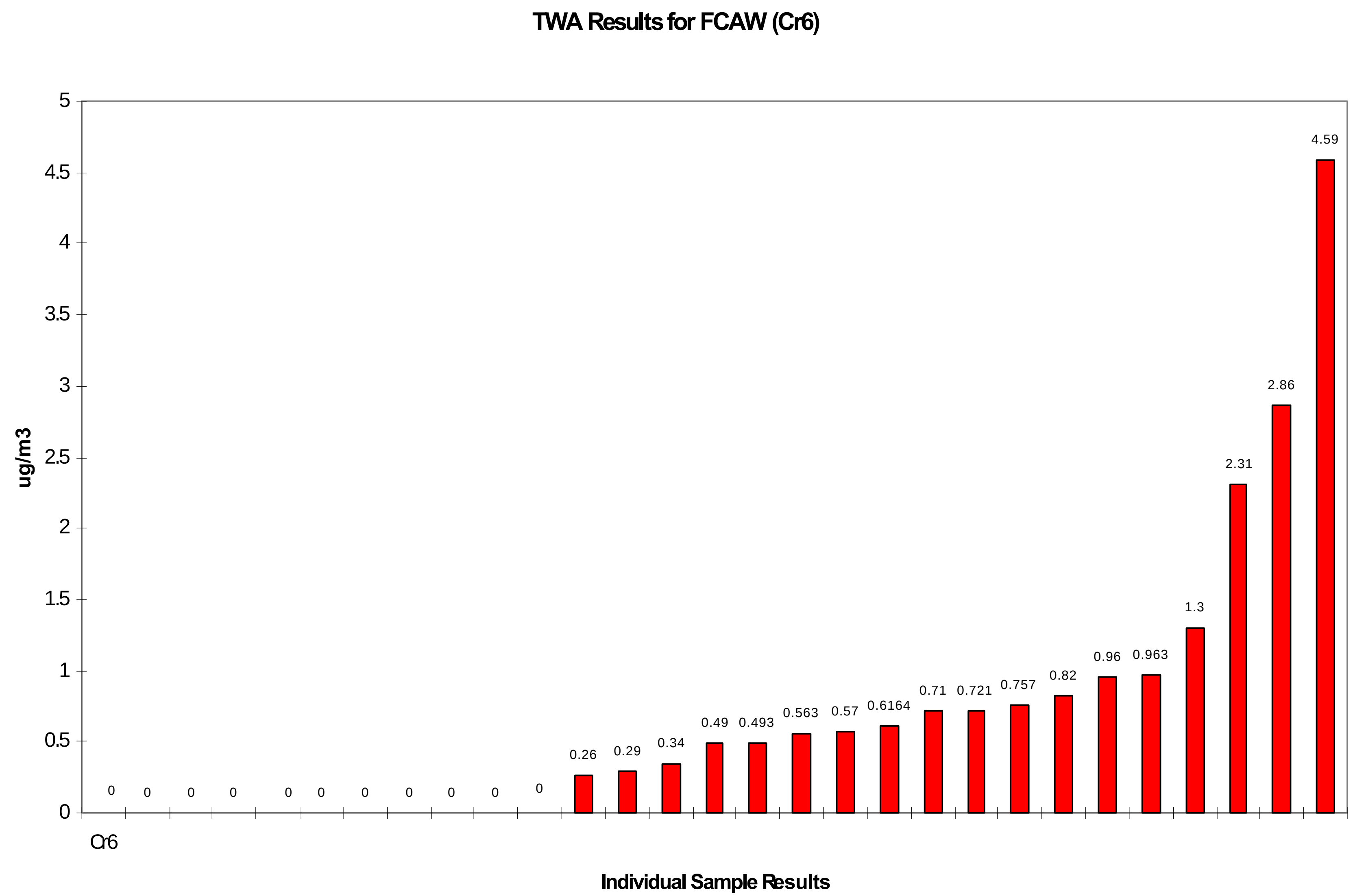


Note: Current OSHA PEL for Ni is 1000 ug/m3 for an 8 hour TWA

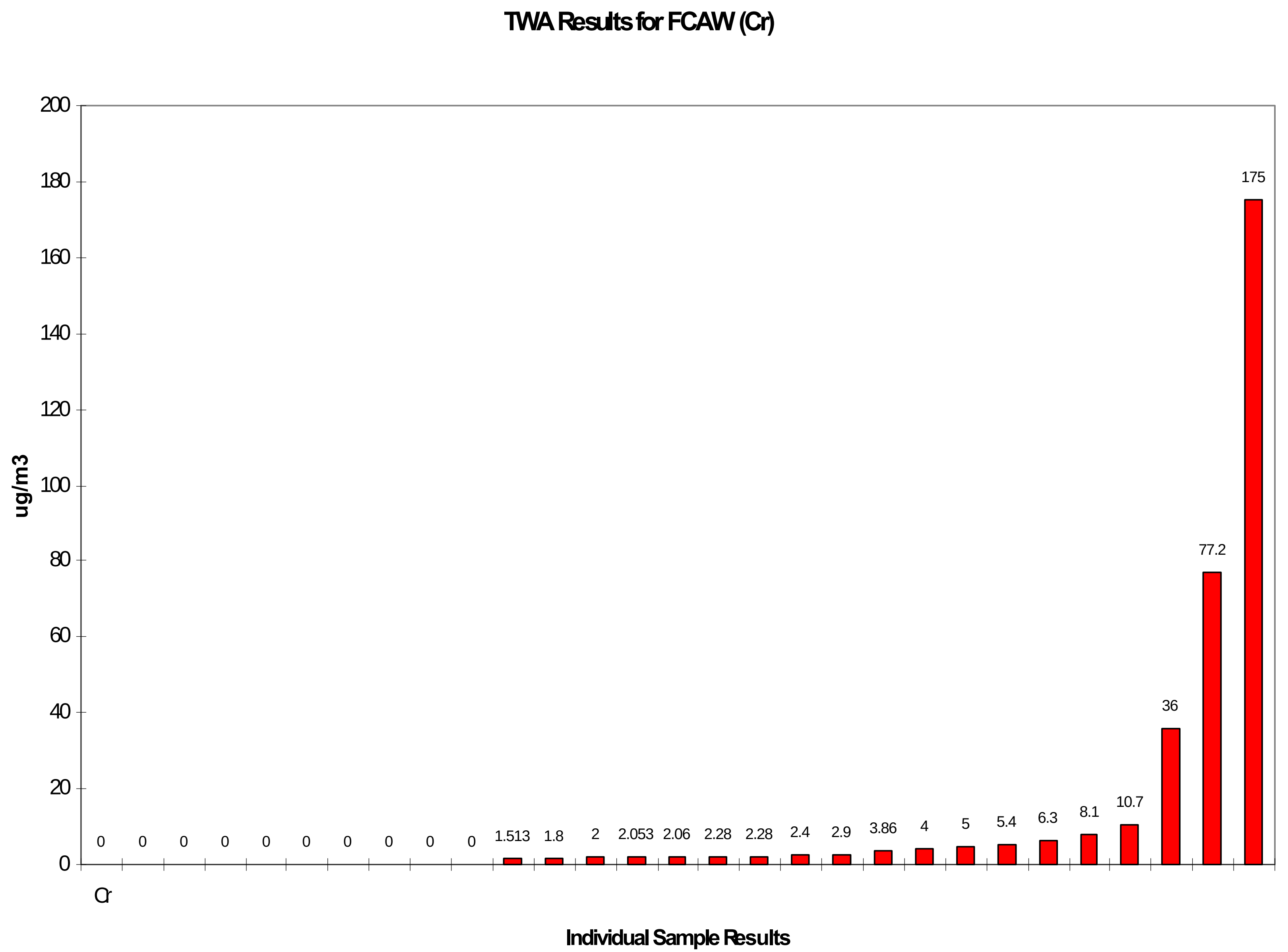
TWA Results for Mn

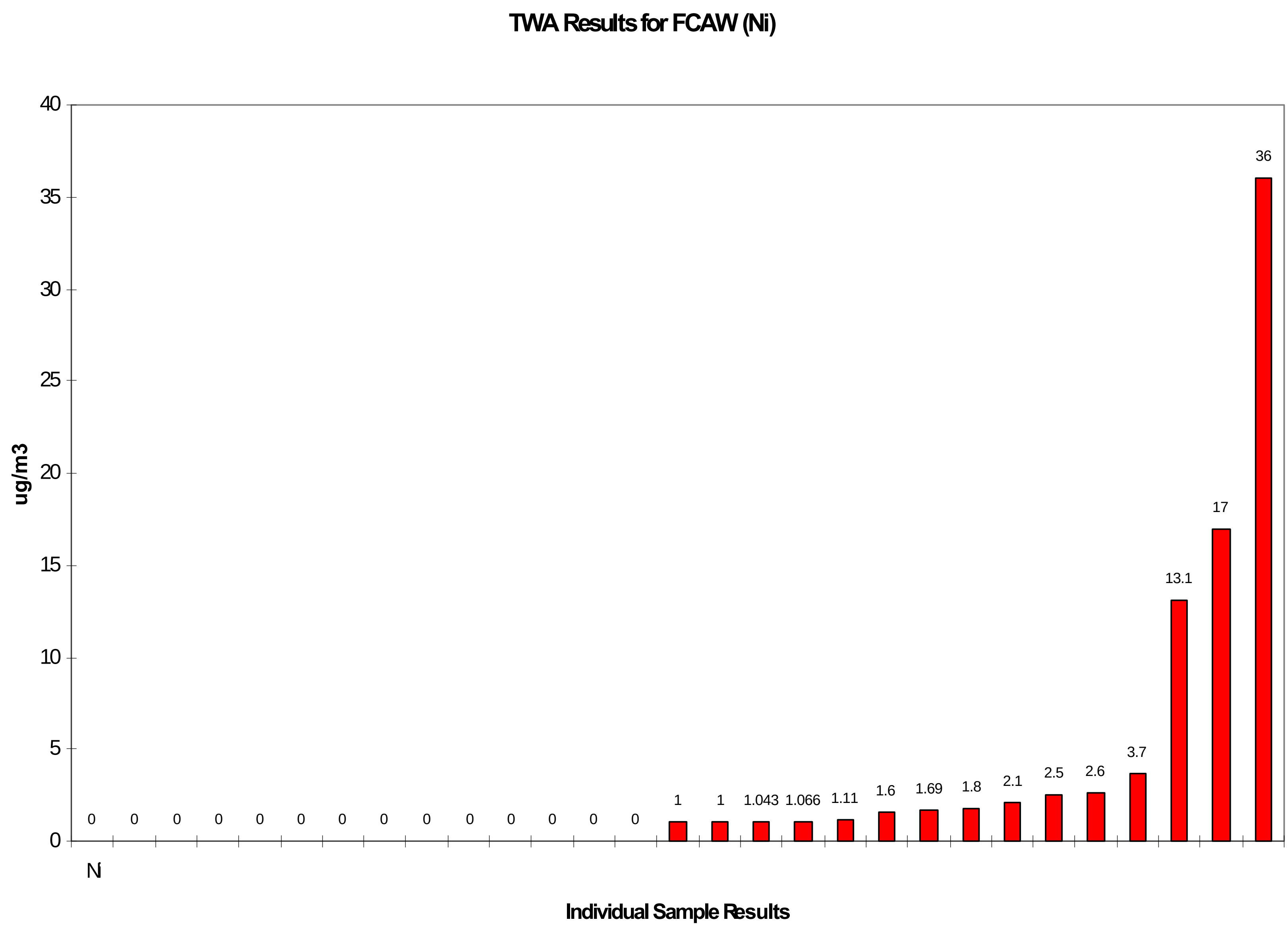


Note: No TWA currently established for Mn. OSHA is evaluating Mn and it is anticipated that a PEL of 200 ug/m3 will be established in the near future.

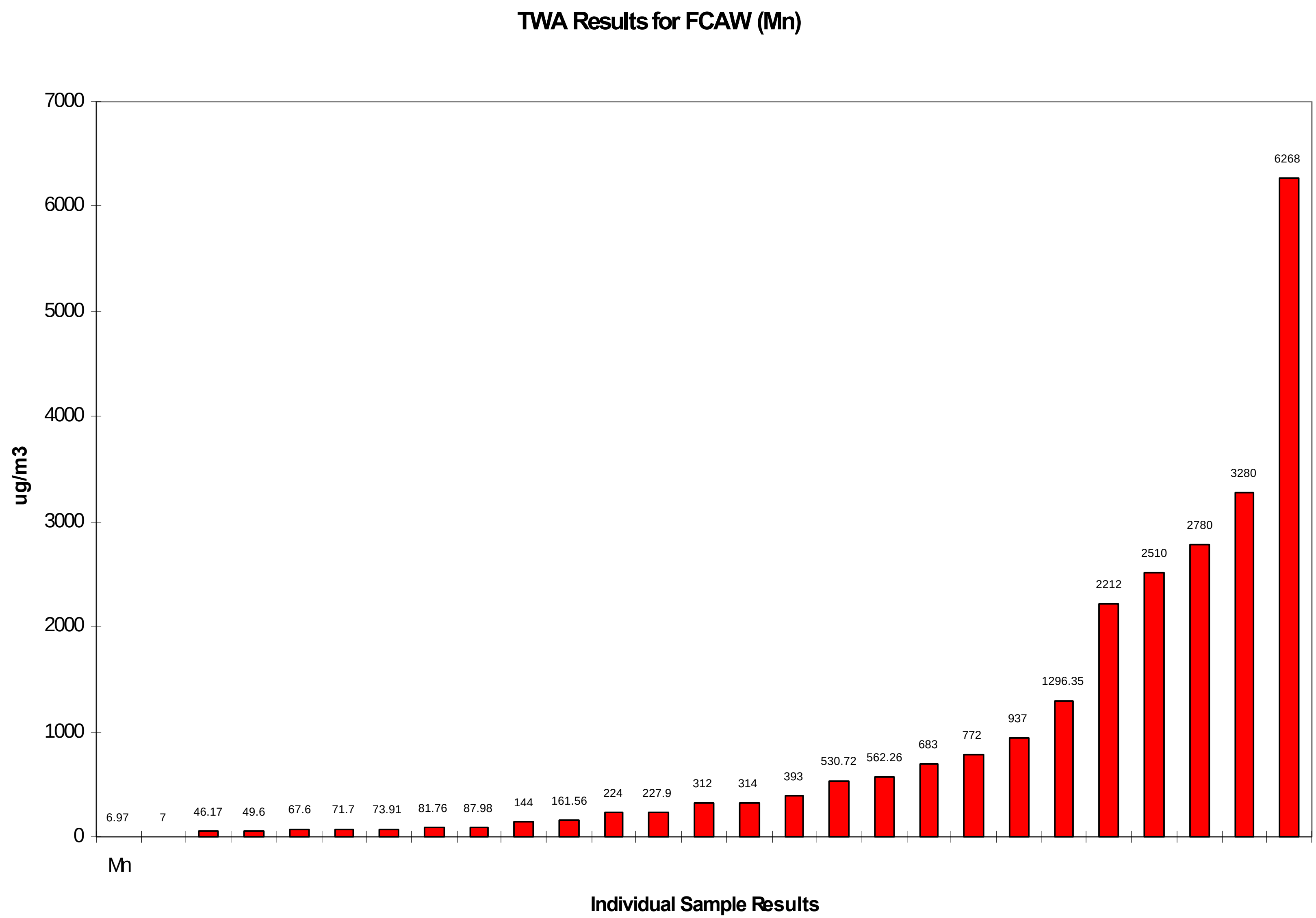


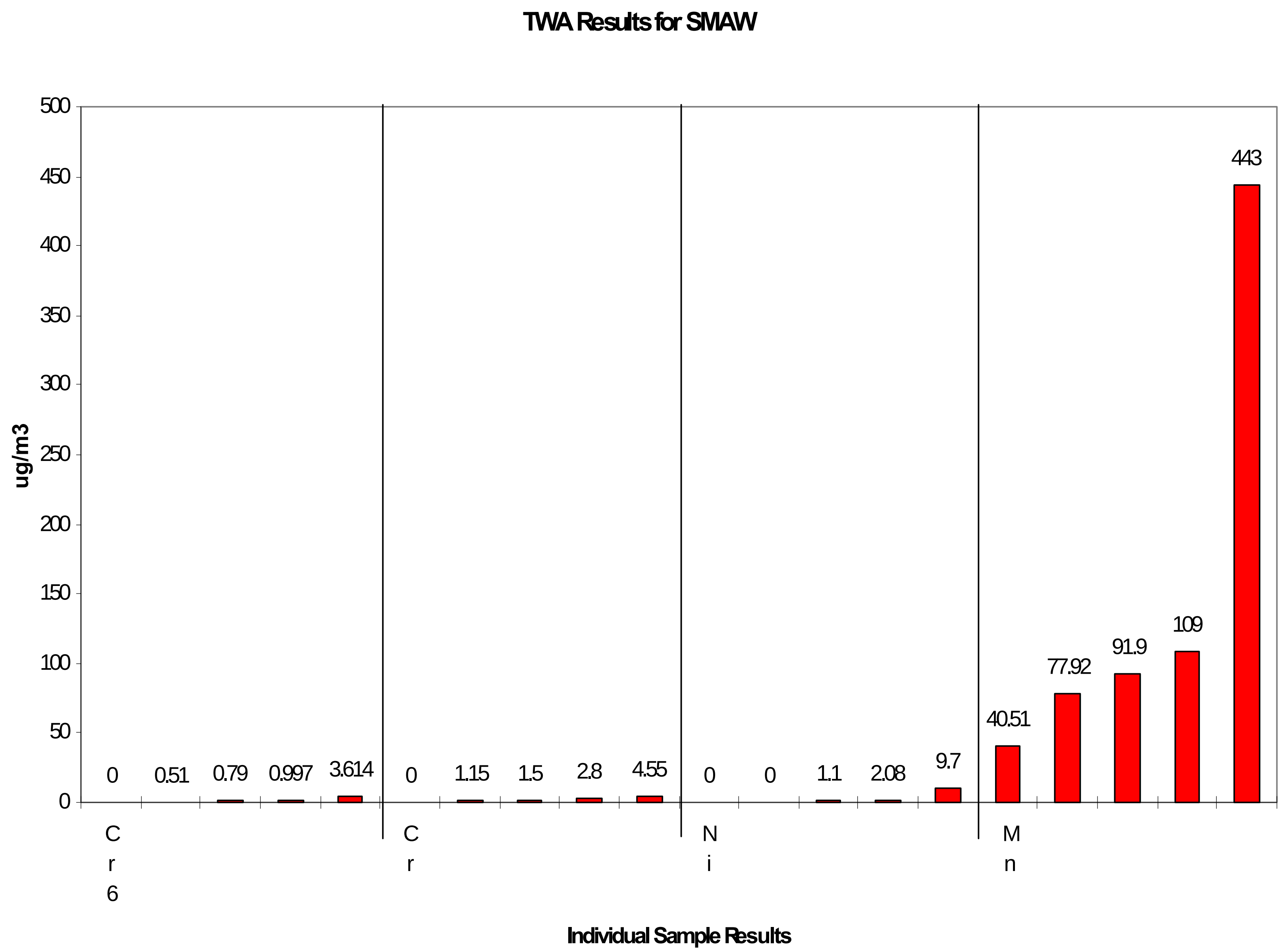
TWA Results for FCAW (Cr6)
ug/m3
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0
0
0
0
0
0
0
0
0
0
0.26
0.29
0.34
0.49
0.493
0.563
0.57
0.6164
0.71
0.721
0.757
0.82
0.96
0.963
1.3
2.31
2.86
4.59
Cr6
Individual Sample Results

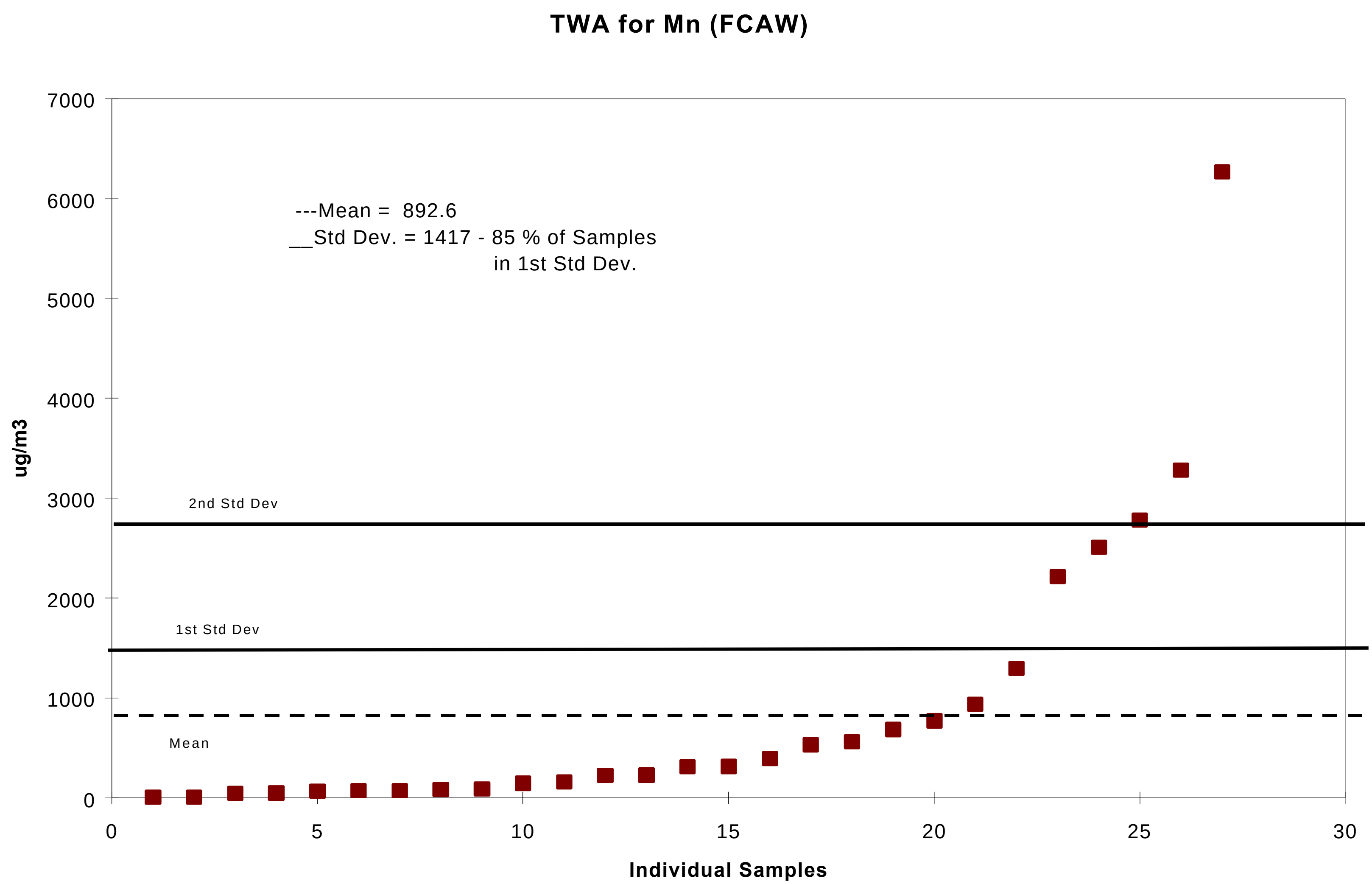

TWA Results for FCAW (Cr)
ug/m3
200
180
160
140
120
100
80
60
40
20
0
0 0 0 0 0 0 0 0 0 0 1.513 1.8 2 2.053 2.06 2.28 2.28 2.4 2.9 3.86 4 5 5.4 6.3 8.1 10.7 36 77.2 175
Cr
Individual Sample Results

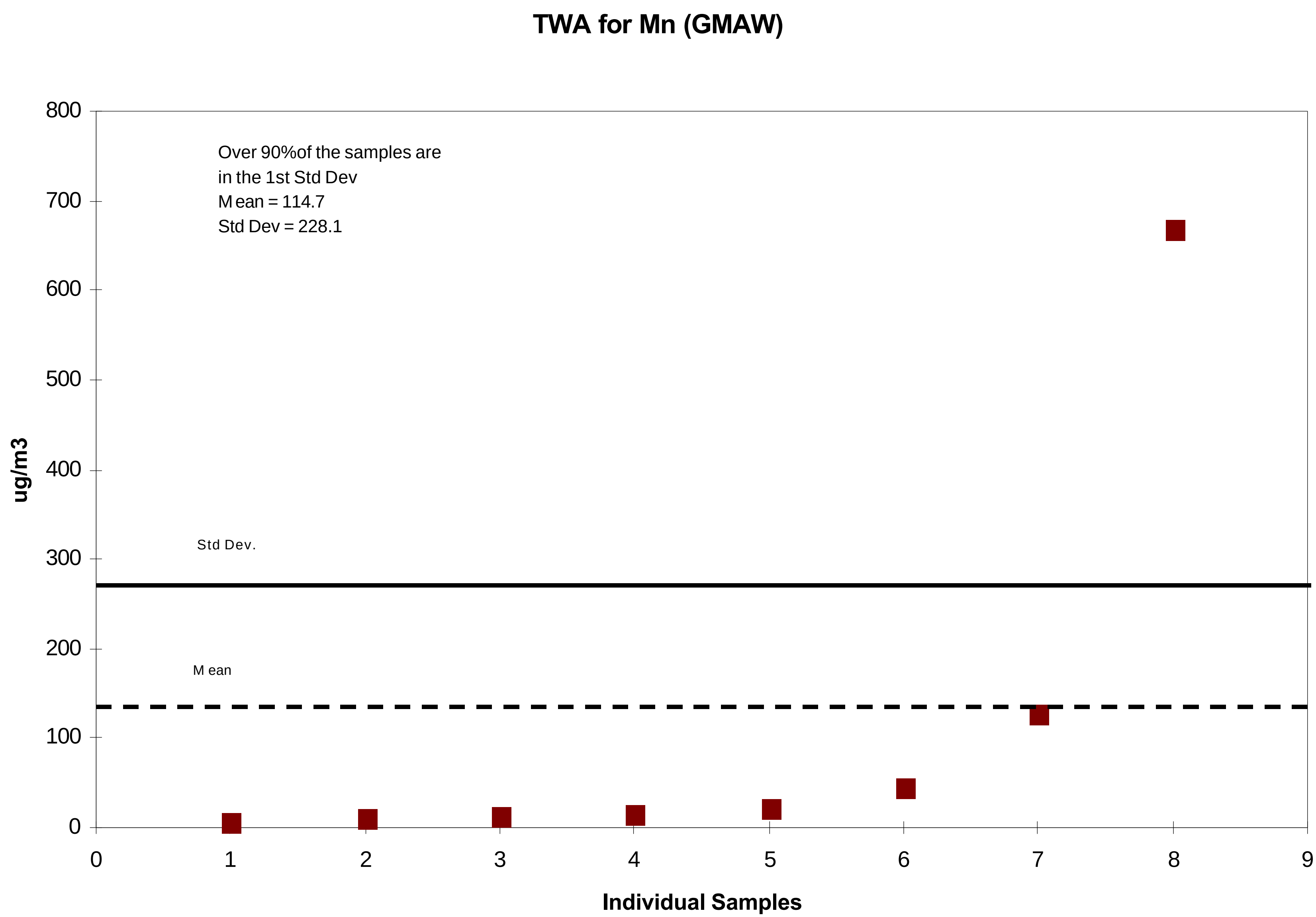


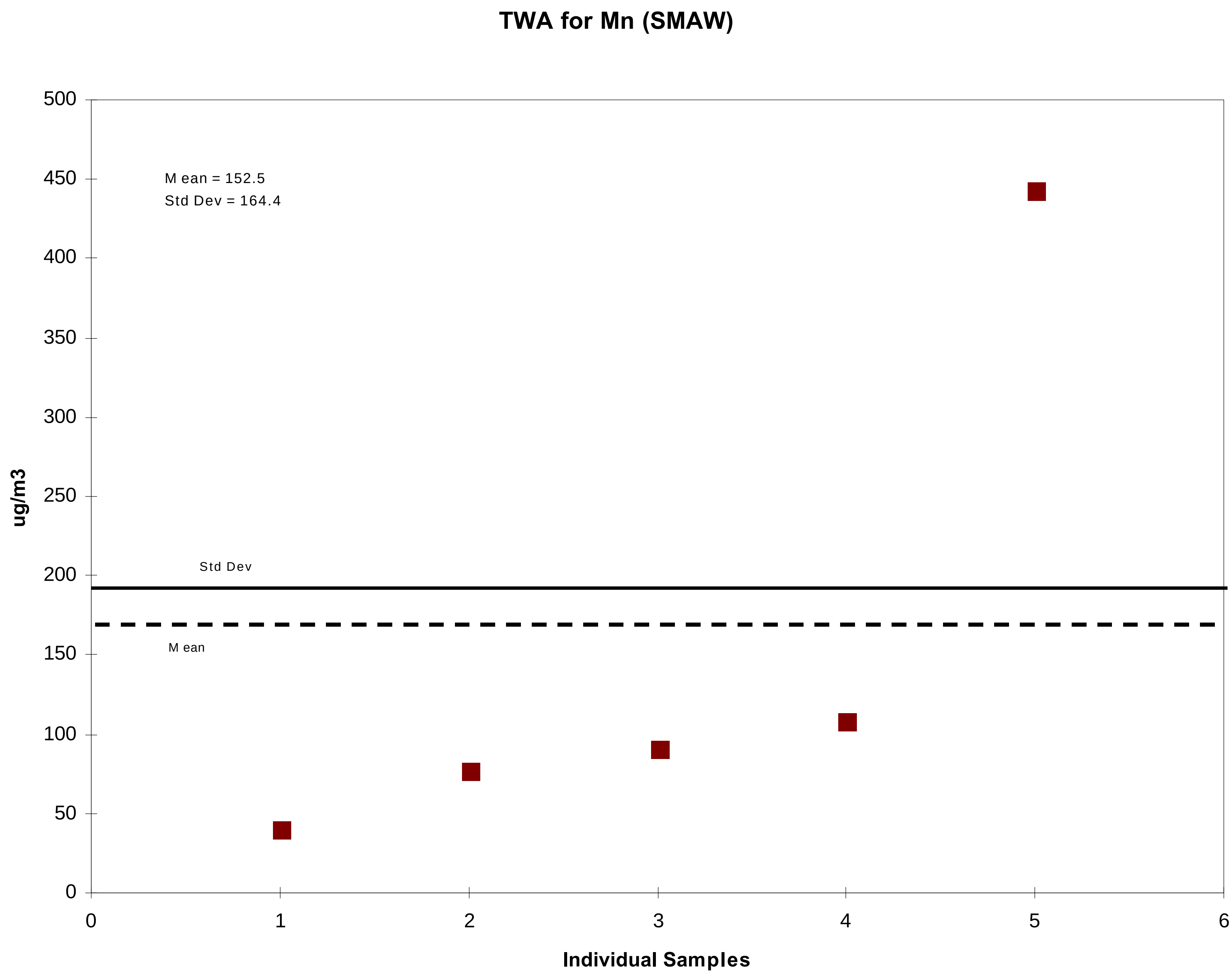
TWA Results for FCAW (Ni)
ug/m3
0
5
10
15
20
25
30
35
40
0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1.043 1.066 1.11 1.6 1.69 1.8 2.1 2.5 2.6 3.7 13.1 17 36
Ni
Individual Sample Results

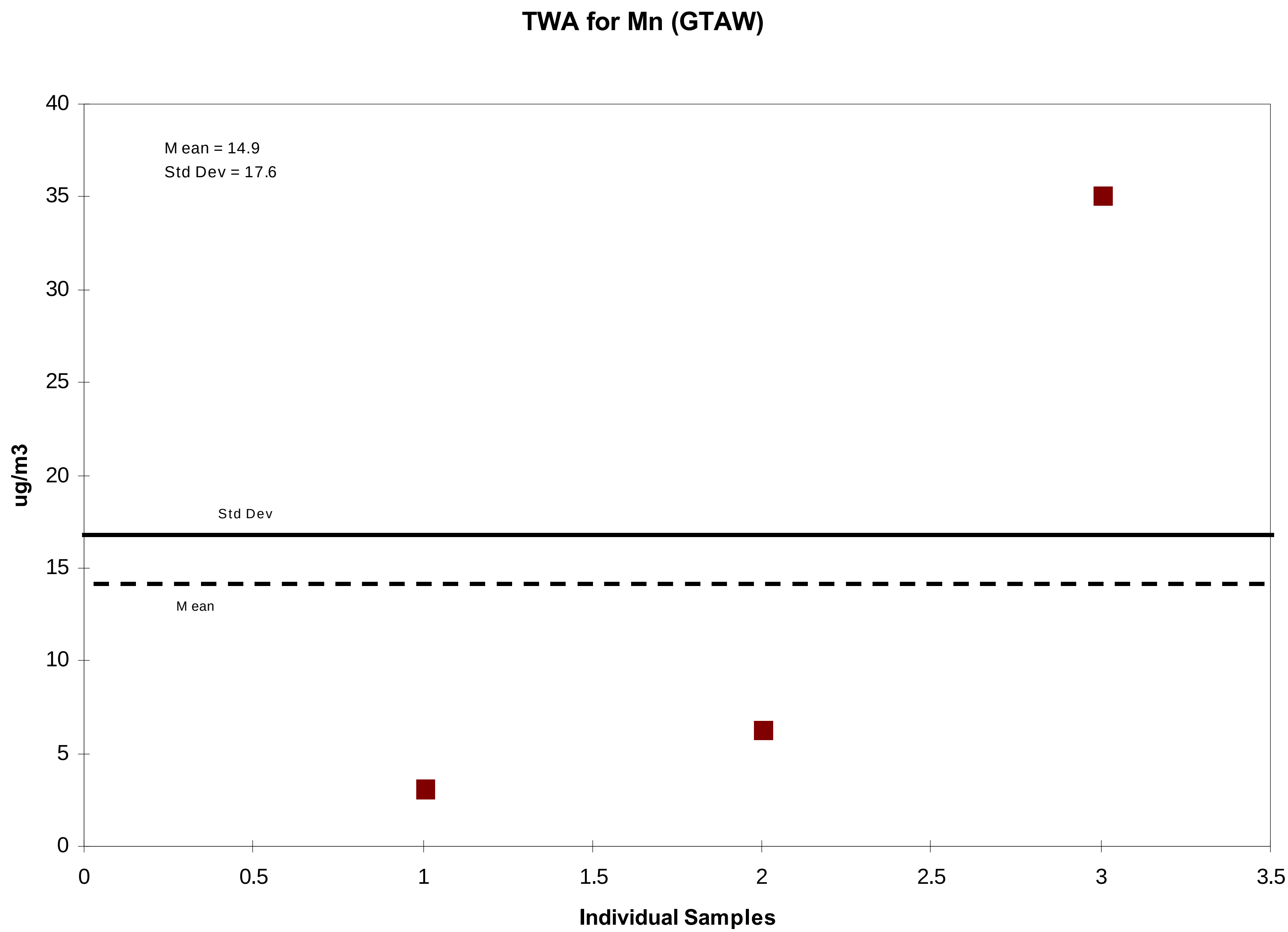

TWA Results for FCAW (Mn)
ug/m3
7000
6000
5000
4000
3000
2000
1000
0
6.97
7
46.17
49.6
67.6
71.7
73.91
81.76
87.98
144
161.56
224
227.9
312
314
393
530.72
562.26
683
772
937
1296.35
2212
2510
2780
3280
6268
Mn
Individual Sample Results


TWA Results for SMAW
ug/m3
500
450
400
350
300
250
200
150
100
50
0
0
0.51
0.79
0.997
3.614
0
1.15
1.5
2.8
4.55
0
0
1.1
2.08
9.7
40.51
77.92
91.9
109
443
Cr6
Cr
Ni
Mn
Individual Sample Results


TWA for Mn (FCAW)
---Mean = 892.6
__Std Dev. = 1417 - 85 % of Samples
in 1st Std Dev.
2nd Std Dev
1st Std Dev
Mean
ug/m3
Individual Samples
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30


TWA for Mn (GMAW)
Over 90%of the samples are
in the 1st Std Dev
Mean = 114.7
Std Dev = 228.1
Std Dev.
Mean
ug/m3
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
Individual Samples


TWA for Mn (SMAW)
Mean = 152.5
Std Dev = 164.4
Std Dev
Mean
ug/m3
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
Individual Samples


TWA for Mn (GTAW)
M ean = 14.9
Std Dev = 17.6
Std Dev
M ean
ug/m3
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
Individual Samples

Final Report

Appendix 4

Photograph 1. Pneumatic powered portable ventilation fan propped over tank hatch cover aboard ship under construction

Photograph 2. Supply air ventilation measurements being collected inside engine room of ship under construction

Photograph 3. Portable fume extraction blower unit used in shipyard

Photograph 4. Portable fume extraction hose on articulating are for easy positioning

Photograph 6. Welding station equipped with portable fume extraction hose on articulating arm

Photograph 5. Fixed fume extraction hose positioned directly above work to be performed

Photograph 7. Portable fume extraction fan hung from ceiling by rope during welding of bulkheads for ship construction

Photograph 8. General shop ventilation fan

Photograph 9. Plasma cutter with no engineering controls in place to capture fumes generated.

Photograph 10. Supply air ventilation measurements being collected inside engine room of ship under construction.

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